Sows' colostrum yield and piglets' colostrum intake: a challenge in high-prolific pig production

Thesis submitted in the fulfilment of the requirements for the degree of Doctor in Veterinary Sciences

Ilse Declerck

Department of Obstetrics, Reproduction and Herd Health

Faculty of Veterinary Medicine

Ghent University

Promotors: Prof. Dr. D. Maes en Prof. Dr. J. Dewulf

TABLE OF CONTENTS

I. GENERAL INTRODUCTION 3

1. Synthesis of colostrum 4

2. Colostrum composition 10

3. Importance of colostrum 18

4. Colostrum production and intake 24

5. Preweaning performance and mortality 36

6. References cited 39

II. AIMS 61

III. LONG-TERM EFFECTS OF COLOSTRUM INTAKE IN PIGLET MORTALITY AND PERFORMANCE 65

IV. SOW AND LITTER FACTORS INFLUENCING COLOSTRUM YIELD AND NUTRITIONAL COMPOSITION 95

V. SOW AND PIGLET FACTORS DETERMINING VARIATION OF COLOSTRUM INTAKE BETWEEN AND WITHIN LITTERS 119

VI. EFFECTS OF ENERGY SUPPLEMENTATION TO NEONATAL (VERY) LOW BIRTH WEIGHT PIGLETS ON MORTALITY, WEANING WEIGHT, DAILY WEIGHT GAIN AND COLOSTRUM INTAKE 145

VII. GENERAL DISCUSSION 169

SUMMARY 195

SAMENVATTING 203

Chapter 1

General Introduction

I. GENERAL INTRODUCTION

During the last decades, average litter size has substantially increased by the introduction of hyper-prolific sow breeds into commercial pig production (Beaulieu et al., 2010; Rutherford et al., 2013). Selection towards larger litters has not only resulted in lower average birth weight, but also in more heterogeneous litters with more low birth weight piglets (Milligan et al., 2002; Quiniou et al., 2002; Quesnel et al., 2008). Birth weight has an overwhelming role in piglet survival and performance and hence, selection towards larger litter sizes has also resulted in higher preweaning mortality (e.g. Milligan et al., 2002; Quiniou et al., 2002; Johansen et al., 2004; Paredes et al., 2012). Larger litters also imply competition at the udder for colostrum intake (Milligan et al., 2001; Andersen et al., 2011; Rutherford et al., 2013) and insufficient colostrum intake has shown to be a major cause of preweaning mortality (Le Dividich et al., 2005; Decaluwé et al., 2014b). In contrast with milk production, the production of colostrum appears to be independent from litter size (Le Dividich et al., 2005; Devillers et al., 2007; Foisnet et al., 2010a; Quesnel et al., 2012), and hence, sufficient colostrum intake per piglet becomes critical in high-prolific sow breeds. Therefore, knowledge on factors determining piglets' colostrum intake, sows' colostrum yield and colostrum composition is needed to maximize sows' and piglets' production potential.

The following literature review describes the synthesis and composition of colostrum, followed by the importance of colostrum in piglets, factors determining and measures improving sows' colostrum yield and piglets' colostrum intake and finalizing with preweaning performance and mortality.

1. SYNTHESIS OF COLOSTRUM

Lactogenesis corresponds with the onset of lactation during late gestation, is characterized by the synthesis of colostrum and lasts till 24 to 48 h after the onset of parturition (Devillers et al., 2006; Farmer et al., 2006). Lactogenesis can be subdivided into lactogenesis I and lactogenesis II (Hartmann and Holmes, 1989; Devillers et al., 2006). Lactogenesis I starts around day 105 of gestation and is characterized by the differentiation of the mammary glands and by the synthesis of colostrum. Lactogenesis II coincides with the drop in the progesterone concentration at parturition and is characterized by the transition from colostrum to milk and the onset of copious milk secretion (Devillers et al., 2006; Farmer et al., 2006; Theil et al., 2006).

At present, it is not exactly known when colostrum is synthesized in the mammary gland. It is believed that most (if not all) of the colostrum is produced during the last seven to ten days of gestation. However, colostrum is probably also synthesized after the onset of farrowing (Theil et al., 2012; Theil et al., 2014a; Theil, 2015). In general, colostrum is defined as the first mammary secretion acquired by neonatal piglets during 24 h after the onset of farrowing. During parturition, colostrum is continuously available. Thereafter, nursings are progressively developed till cyclic letdowns occur around 10 to 12 h after the start of parturition (de Passillé and Rushen, 1989; Devillers et al., 2004b; 2006; 2007).

1.1. Mechanism of colostrum synthesis

Mammary gland development in gilts and changes during lactogenesis

At birth, the mammary glands consist mainly of subcutaneous stromal tissue with a rudimental duct system (Hughes and Varley, 1980). Around 90 days of age, mammary tissue increases and an extensive duct system is established by the time of puberty (Turner, 1952). In gilts that have reached puberty, the mammary parenchym increases by around 51%, whereas the extraparenchymal tissue decreases with around 16% versus gilts of a similar age that have not started cycling, which indicates that puberty has a stimulatory effect on mammogenesis. (Farmer et al., 2004). During the first two-thirds of gestation, mammary glands in pregnant gilts remain small. After day 75 of gestation, there is accelerated mammary accretion and tissue differentiation with a shift from a high lipid content to a high protein content in mammary glands (Sorensen et al., 2002; Ji et al., 2006). Around day 90 of gestation, mammary glands in gilts are structurally complete with maximum cell concentrations (Devillers et al., 2006).

During gestation, there is functional differentiation of the epithelia and accumulation of secretion in the alveoli between day 90 and day 105 of gestation. Around day 112 of gestation, the lumina of the alveoli are distended due to colostrum secretion (Devillers et al., 2006; Farmer et al., 2006), and colostrum can be manually extracted already some days before farrowing (Devillers et al., 2006). Before parturition, the tight junctions between mammary epithelial cells are leaky, which enables exchange between the extracellular space and the alveolar lumen (Farmer et al., 2006). During lactogenesis II, tight junctions become closed (Farmer et al., 2006) and along with the establishment of this blood milk barrier, colostrum is gradually replaced by milk and the synthesis of lactose increases (Klobasa 1987; Shennan and Peaker, 2000). A tight junction barrier is essential to prevent loss of milk components (e.g. lactose) from the alveolar lumen into the circulation and hence, to enable copious milk secretion. The integrity of the mammary epithelium, established by the mammary gland barrier, is negatively associated with the Na/K ratio in colostrum (Shennan and Peaker, 2000; Foisnet et al., 2010a). However, Quesnel (2011) did not observe a relationship between colostrum yield and the Na/K ratio in colostrum, whereas Foisnet et al. (2010a) and Loisel et al. (2015) attributed low colostrum yield to leaky mammary epithelium based on the high Na/K ratio in colostrum.

Secretion of colostrum components

There are four different routes to transport colostral components to the alveolar lumen, which are illustrated in **Figure 1**. Paracellular transport occurs only during the period of colostrum production, whereas the other transport routes occur during colostrum as well as milk production (Devillers et al., 2006).

Paracellular transport (Figure 1 (1))
Paracellular transport represents the transport between the mammary epithelial cells via leaky tight junctions. Immune cells, immunoglobulins and electrolytes reach the alveolar lumen this way (Shennan and Peaker, 2000; Klopfenstein et al., 2002). However, colostrum cannot be simplified as a transudation product from plasma as the different colostrum components have different plasma-to-colostrum ratios. Hence, there must be some kind of specific regulation, but the underlying mechanism how components from the plasma are transferred to colostrum is not yet described (Devillers et al., 2006).

Exocytosis (Figure 1 (2))
Vesicles formed by the endoplasmatic reticulum and the Golgi-apparatus are transported towards the apical membrane of the mammary epithelium, with which vesicle membranes fuse and hence, the content of the vesicles is secreted into the alveolar lumen. Exocytosis permit the transport of proteins, lactose and monovalent electrolytes (Klopfenstein et al., 2002; Devillers et al., 2006).

Secretion of lipid drops (Figure 1 (3))
Lipid drops formed in the cytoplasm, migrate to the apical membrane, which surrounds the lipid drops during and after secretion (Keenan, 2001). The lipid drops also contain lipid soluble hormones, vitamins, leptin, and some growth factors (Shennan and Peaker, 2000).

Transcellular transport (Figure 1 (4))
At the basal side of the epithelial cells, some components surrounded by membrane enter the cell. These vesicles are transported through the cells towards the apical membrane. The membranes of the vesicles fuse with the apical membrane of the mammary epithelium and hence, the content of the vesicles are secreted into the alveolar lumen. Immunoglobulins, growth factors and hormones are transported this way (Shennan and Peaker, 2000; Klopfenstein et al., 2002; Devillers et al., 2006).

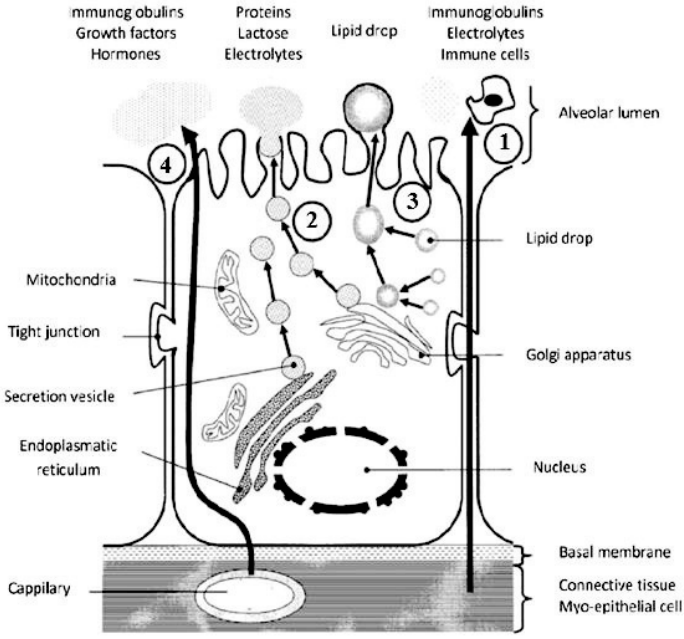

Figure 1. Illustration of the four different transport routes of nutrients to the alveolar lumen in the mammary gland. 1: paracellular transport, 2: exocytosis, 3: secretion of lipid drops, 4: transcellular transport (adapted from Devillers et al., 2006).

1.2. Hormonal control of colostrum synthesis

The peripartal period is characterized by changes in progesterone, estrogen, prolactin, relaxin, cortisol and oxytocin. Most hormones involved in the parturition process are also involved in colostrum production (Wilcox et al., 1983; Delouis et al., 2001; Devillers et al., 2004b, 2006). At the end of gestation, the strong decrease of **progesterone** concentration allows the initiation of farrowing and the prepartum peak of prolactin, which triggers lactogenesis. High progesterone levels around farrowing are associated with lower lactose levels in colostrum (Willcox et al., 1983; Holmes et al., 1993), lower colostrum yield (Devillers et al., 2004a; Foisnet et al., 2010a), lower piglet weight gain (Foisnet et al., 2010a) and increased piglet mortality (de Passillé et al., 1993). Some authors reported that administration of progesterone to sows during late gestation suppressed the increase of colostral lactose (Gooneratne et al., 1979; Whitely et al., 1990), whereas others (Foisnet et al., 2010b) did not find an association

between progesterone supplementation and lactogenesis. Plasma **estrogen** concentrations increase at the end of gestation, peak at parturition and drop with the removal of the placentas, which are a source of estrogen (Devillers et al., 2004a). No direct effect of estrogen on lactogenesis was observed in sows (Tucker, 1981; Willcox et al., 1983), however the decrease in progesterone and the increase in estrogen are necessary for lactogenesis by high levels of prolactine (Falconer et al., 1983; Willcox et al., 1983; Devillers et al., 2004a). The prepartum peak in **prolactin** is necessary to trigger and guarantee successful lactogenesis (Farmer, 2001). Prolactin stimulates the synthesis of caseins, alfa-lactalbumine, fatty acids and lactose (Plaut et al., 1989; Delouis et al., 2001). Lactose is the principal osmotic component in the mammary secretions and hence, limited lactose production limits water transfer into the alveolar lumen and hence, limits colostrum volume (Leong et al., 1990). Sows with low colostrum yield had lower plasma prolactin concentrations versus sows with high colostrum yield (Foisnet et al., 2010a; **Figure 2**). Administration of bromocriptine, an inhibitor of prolactin synthesis, to sows during late gestation suppressed lactation (Whitacre and Threlfall, 1981; Taverne et al., 1982; Farmer et al., 1998). It seems that the secretory capacity by the mammary epithelium depends on the combination of the sudden withdrawal of progesterone with the drastic prolactin increase (Falconer, 1980; Willcox et al., 1983; Devillers et al., 2004a). A delayed progesterone decrease and a delayed prolactin increase were observed in sows with lower colostral lactose and lower colostrum yield (Foisnet et al., 2010a; **Figure 2**). Loisel et al. (2015) emphasize the relative concentrations between progesterone and prolactin before farrowing as sows with a high versus low prolactin-to-progesterone ratio had a higher colostrum yield. **Relaxin** seems to have no specific influence on colostrum production (Zaleski et al., 1996; Devillers et al., 2006). One study observed a positive correlation between plasma **cortisol** around farrowing and the colostral lactose concentration (Willcox et al., 1983) as cortisol might induce more prolactin receptors at the mammary epithelium (Tucker 1981). **Oxytocin** stimulates contraction of the myoepithelial cells surrounding the alveoli, resulting in milk ejection (Ellendorf et al., 1979), but its role regarding the initiation of lactogenesis remains unclear (Ollivier-Bousquet and Devinoy, 2005; Devillers et al., 2006).

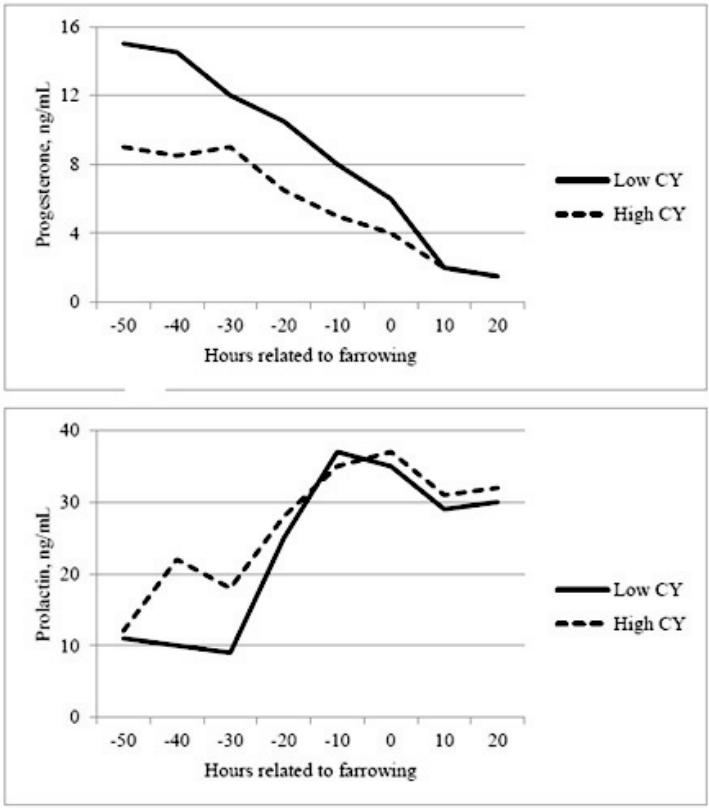

Figure 2. *Plasma concentrations of progesterone and prolactin around farrowing in sows with low (< 1.4 kg) or a high (> 2.8 kg) colostrum yield (adapted from Foisnet et al., 2010a).*

2. COLOSTRUM COMPOSITION

Colostrum is considered as the elixir of life because it contains several components affecting piglets' survival and proper development (Theil et al., 2014b). Colostrum has lower concentrations of lactose and fat, but a higher percentage of dry matter and protein compared to milk (Klobasa et al., 1987; Theil et al., 2014b). Many colostral components change rapidly over time and hence, in terms of colostrum composition it is important to distinguish early (0 h), mid (12 h) and late (24 h) colostrum (Theil et al., 2014b). The switch from colostrum into milk occurs between 24 and 36 h after the onset of parturition and is characterized by an increase in lactose and fat concentration and by a strong decrease in immunoglobulins (Klobasa et al., 1987; Gallagher et al., 1997).

2.1. Lactose

Theil et al (2014b) described that at parturition, the lactose content averages 3.5% and increases to 4% and 4.4% in mid and late colostrum, respectively (**Figure 3**), which is consistent with earlier work about colostrum composition by Klobasa et al. (1987). Lactose is the major osmotic component and hence, determines the amount of mammary secretions (Leong et al., 1990; Foisnet et al., 2010a). Lactose varies only within a narrow range. This implies that because of its osmotic function, increased lactose production will affect mainly colostrum yield instead of colostrum composition (Theil et al., 2014b). Colostral lactose supplies energy to neonatal piglets (Theil et al., 2014b).

Colostral lactose is lower in Meishans than in white sow breeds (Zou et al., 1992) and lower in Belgian Landrace/Piétrain and Duroc sire lines than in Yorkshire (Farmer et al., 2007). Colostral lactose was not influenced by farrowing induction applied at day 112 of gestation (Jackson et al., 1995), whereas higher colostral lactose in early colostrum was observed in sows induced at day 113 of gestation when compared to sows with a natural gestation length of 113 days (Foisnet et al., 2011). In the study of Heo et al. (2008), fat supplementation at the end of gestation was related with a higher lactose content in colostrum. Isley et al. (2003) observed a tendency to higher lactose concentrations in sows fed plant extracts (carvacrol, cinnamaldheyde, capsicum) at the end of gestation. Theil et al. (2014a) noticed higher

colostral lactose levels in sows fed pectin residue or sugarbeet pulp versus potato pulp or low-fiber diet during gestation.

2.2. Fat

In early and mid-colostrum, the fat content averages 5.1 to 5.3%, respectively and increases to 6.9% in late colostrum (Theil et al., 2014b; **Figure 3**). These averages are slightly higher than described by Klobasa et al. (1987). The fatty acids in colostrum are mainly oleic acid, palmitic acid, linoleic acid and stearic acids, whereas short chain fatty acids are almost absent (Csapo et al., 1996). Colostral fat is a great source of energy to neonatal piglets (Herpin et al., 2002). Increased colostral fat may depress piglets' colostrum intake. However, the overall energy intake is higher because the higher fat level compensates more than the decreased intake (Le Dividich et al., 1997).

Meishan have more colostral fat than white sow breeds (King et al., 1996). Parturition induction on day 112 of gestation decreases colostral fat concentration (Jackson et al., 1995). Sows supplemented with exogenous porcine growth hormone or injected with prolactin have higher colostral fat levels (Spence et al., 1984; King et al., 1996). Especially sow nutrition can alter fat content and fatty acid composition in colostrum. Severe feed restriction (1.0 vs 3.4 kg/day) during the last 14 days of gestation results in higher colostral fat content (Göransson, 1990; Mahan, 1998). Fat supplementation during late gestation increases colostral fat (Boyd et al., 1982; Jackson et al., 1995; Heo et al., 2008). Many studies aimed to increase the amount of polyunsaturated fats by supplementing fish oil in the gestation diet. Salmon and tuna oil, for instance, increase the long-chain n-3 fatty acids, particularly 22:6 n-3 at the expense of n-6 fatty acids (Taugbol et al., 1993; Rooke et al., 2000). Supplementation of the sow diet with conjugated linoleic acid during end of gestation and lactation tended to increase colostral fat (Krogh et al., 2012). The level of protein in feed has no influence on colostral fat content (Mahan, 1998). Supplementation of fiber during the last 10 days of gestation increases the fat content of late colostrum (Loisel et al., 2013), whereas Theil et al. (2014a) reported lower fat levels in colostrum from sows fed pectin residue or sugarbeet pulp versus potato pulp or low-fiber diet during gestation.

2.3. Protein

At farrowing the protein content averages 17.7%, but decreases drastic to 12.2% within 12 h after parturition and further to 8.6% in late colostrum (Theil et al., 2014b; **Figure 3**). These changes are similar to those reported by Klobasa et al. (1987). Colostral proteins can be divided into caseins and whey proteins. The ratio between caseins and whey proteins changes from 9:90 at onset of farrowing to 47:53 one day after parturition (Xu, 2003). Caseins are a source of dietary amino acids, are a carrier of calcium or may act as bioactive compounds after digestion (Xu, 2003). Whey proteins consist of albumin, α-lactalbumin, β-lactoglobulin, IgG, IgA, IgM, lactoferrin, and other minor proteins (Csapo et al., 1996; Gallagher et al., 1997). Up to 80% of colostral proteins are immunoglobulins (Klobasa et al., 1987), which are described in a separate section. Colostral proteins have mainly immunological and bioactive functions rather than the supply of energy (Mellor and Cockburn, 1986; Theil et al., 2014b).

Colostral protein has shown to be higher in Duroc compared to Landrace and Yorkshire (Farmer et al., 2007). Injection with exogenous porcine growth hormone on day 100 of gestation results in lower colostral protein (King et al., 1996). A higher protein level or fermented liquid feed in late gestation has no influence on colostral protein level (Al-Matubsi et al., 1998; Demeckova et al., 2003). Regarding the association between colostral protein and fiber, Theil et al. (2014a) observed lower protein levels in colostrum from sows fed pectin residue or sugarbeet pulp versus potato pulp or low-fiber diet during gestation.

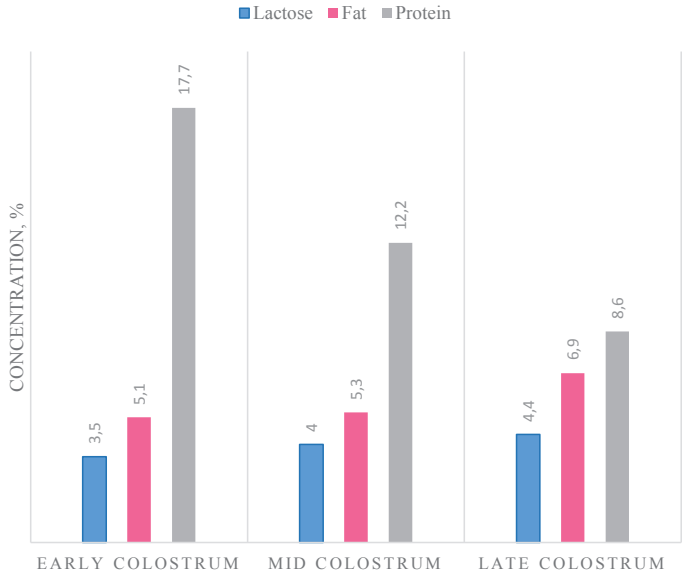

Figure 3. *Average composition (%) of early (0 h), mid (12 h) and late (24 h) colostrum (adapted from Theil et al., 2014b).*

2.4. Immunoglobulins

At farrowing, immunoglobulins (**Ig**) represent 50% of the colostral dry matter, whereas 24 h later this is decreased to 15% of the dry matter (Klobasa et al., 1987). IgG is the most abundant isotype in colostrum (81%) (Klobasa et al., 1987; Butler, 1974; Wagstrom et al., 2000). The concentration of IgG in colostrum decreases drastically during parturition (Quesnel, 2011; Kielland et al., 2015) till 24 h after farrowing (Klobasa and Butler, 1987; Foisnet et al., 2010a; Quesnel, 2011; **Figure 4**). Hence, IgA becomes the most abundant isotype in sow milk (70%) (Wagstrom et al., 2000). Almost 100% of IgG is derived from sow serum (Bourne et al., 1973) and is transferred from the blood to mammary secreta by the neonatal Fc receptor (FcRn). Unlike IgG, IgA in colostrum originates partly (40%) from maternal serum and mainly from plasma cells, which have migrated from the gut and upper respiratory tract to the mammary gland during the end of gestation. The secretion of IgA from the blood into colostrum is mediated by polymeric Ig receptor (pIgR) in the mammary gland (Salmon et al., 2009).

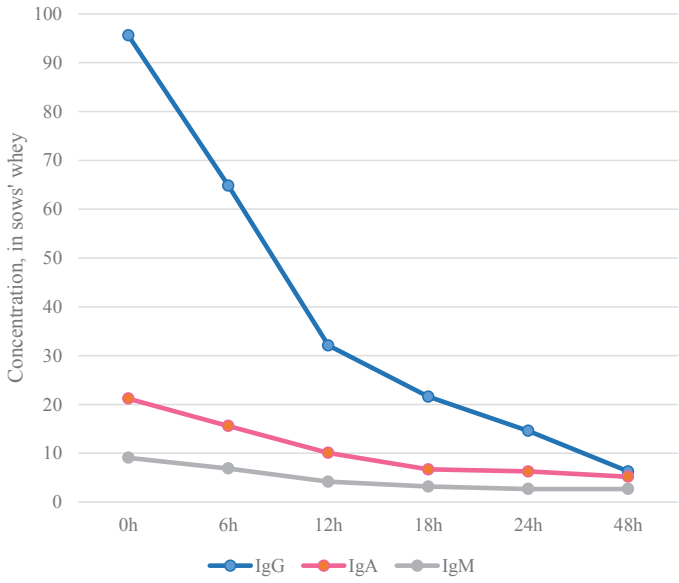

Figure 4. *Concentrations of IgG, IgA and IgM in sows' whey during lactation (adapted from Klobasa et al., 1987).*

The IgG level in colostrum is very variable, even within herds, and is mostly due to sow-to-sow variation (Klobasa and Butler, 1987; Farmer and Quesnel, 2009). Research is needed to know whether IgG concentrations are consistent between lactations in the same sow (Rooke and Bland, 2002). Concentrations of IgG vary with genotype (Quesnel, 2011). The amount of IgG in colostrum is not influenced by farrowing induction (Milon et al., 1983; Jackson et al., 1995, Foisnet et al., 2011). Multiparous sows are reported to provide better passive immunity than primiparous sows (Carney-Hinkle et al., 2013). Quesnel (2011) observed a positive relationship between parity and the level of IgG in late, but not in early colostrum, whereas Kielland et al. (2015) found no significant parity effect on colostrum IgG. Caudal teats tend to have lower IgG concentration than cranial teats (Bland and Rooke, 1998). Also sows' vaccination status can affect the level of colostrum IgG (Bourne et al., 1975). However, sows with identical vaccination schemes may have totally different IgG levels in colostrum (Kielland et al., 2015), probably because of the inherent individual differences of immunoreaction (Gudding, 2010). Le Dividich et al. (2005) mentioned that vaccination might

increase titers of specific antibodies rather than altering the total amount of IgG. Seasonal variations in concentrations of IgA and IgG in colostrum have been described by Inoue et al., 1980; 1981. Cold stress during the last 10 d before farrowing increases the IgG absorption by piglets (Bate and Hacker, 1985). Some nutritional interventions can increase the level of IgG in sow colostrum, such as supplementing long-chain n-6 and n-3 fatty acids (Mitre et al., 2005), supplementation of conjugated linoleic acid during the last days of gestation (Bontempo et al., 2004; Corino et al., 2009) or supplementation of seaweed (extracts) (Leonard et al., 2012). Supplying mannan oligosaccharides (Newman and Newman, 2001; O'Quinn et al., 2001) or fermented liquid feed (Demeckova et al., 2003) improved immunoglobulin concentrations in colostrum. Supplementing vitamins A, C or E to gestating sows improves IgG status of piglets through increased efficiency of absorption rather than by modifying colostrum composition (Nemec et al., 1994; Bland et al., 2001; Pinelli-Saavedra et al., 2008). IgG in colostrum is not related with colostrum yield (Foisnet et al., 2010a) and is positively related with plasma IGF-I (Foisnet et al., 2010a) and the Na/K ratio in late colostrum (Quesnel, 2011; Foisnet et al., 2010a), and negatively related with colostral lactose content (Foisnet et al., 2010a). The positive association of IgG with the Na/K ratio and the negative association with lactose are probably controlled by prolactin. Namely, prolactin is negatively related with IgG transfer (Barrington et al., 1999), stimulates the closure of tight junctions and stimulates the synthesis of lactose (Shennan and Peaker, 2000). However, Foisnet et al. (2010a) did not observe a relationship between IgG and plasma prolactin.

2.5. Cells

Neutrophils and **lymphocytes** are the predominant cells in colostrum. **Macrophages**, **eosinophils** and **epithelial cells** can also be detected (Wuryastuti et al., 1993). Cell types and numbers are dependent on the individual conditions and the developmental stage of the mammary gland (Salmon et al., 2009). Only maternal colostral cells can cross the intestinal epithelium of the piglet, whereas colostral cells from unrelated animals or heat-treated colostral cells or maternal peripheral blood leukocytes are unable to cross the intestinal epithelium (Tuboly et al., 1988; Williams, 1993; Bandrick et al., 2011).

2.6. Vitamins and minerals

Vitamin A is higher in colostrum than milk and its level is influenced by dietary source (Coffey et al., 1982; Lauridsen and Danielsen, 2004; Hyeing et al., 2013). **Vitamin D** has the highest concentration in early colostrum, whereas **vitamin K** is not affected by stage of lactation (Csapo et al., 1996). Colostrum contains much higher amounts of **vitamin E** and **selenium** compared to milk (Mahan et al., 2000). Mahan et al. (2000) observed the highest colostral vitamin E levels in sows with parity two or three. Vitamine E content in the adipose tissue of the sow determines substantially its concentration in colostrum (Hakansson et al., 2001). Injection of vitamin E the week before farrowing (Chung and Mahan, 1995) or supplementing vitamin E during late gestation increases colostral vitamin E (Lauridsen and Jensen, 2005; Pinelli-Saavedra et al., 2008). Colostrum contains higher concentrations of **vitamin C** versus milk. Vitamin C does not increase by supplementing it during late gestation (Mahan and Vallet, 1997). Information on the **B vitamins** in sow colostrum is limited. **Ash** represents the total of inorganic components. Around parturition, ash content of colostrum averages 0.68% and increases during lactation (Hurley, 2015). **Calcium** and **phosphate** are relatively low in colostrum and are independent of the dietary level (Miller et al., 1994). **Potassium**, **sodium**, **chloride**, **sulfur**, **copper**, **iron**, **iodine**, **manganese** and **zinc** are more present in colostrum than in milk (Coffey et al., 1982; Csapo et al., 1996; Peters et al., 2010).

2.7. Hormones, growth factors and other

At parturition, colostrum contains high levels of **progesterone** (Devillers et al. 2004a), **oestradiol** (Devillers et al. 2004a), **oestrone** (Farmer et al., 1987), **prolactin** (Devillers et al. 2004a), **somatotropin** (Farmer et al., 1992) and **relaxin** (Yan et al., 2006), which declines rapidly postpartum. High colostral concentrations of **gastrointestinal hormones** were observed for insulin, neurotensin and bombesin (Weström et al., 1987). The level of **leptin** is higher in colostrum than in sows' circulation and plays a role regarding neonatal growth and physiology (Estienne et al., 2000). Leptin concentrations may vary between breeds as they are shown to be higher in Yorkshire x Meishan crossbreeds than in Meishan sows (Mostyn et al., 2006). Furthermore, **gastrointestinal growth factors** such as IGF-I, IGF-II (Simmen et al., 1988; Monaco et al., 2005), epidermal growth factor (EGF) (Jaeger et al., 1987; Odle et al., 1996) and transforming growth factor-β (Xu et al., 2000) are highest at the day of farrowing.

Fat supplementation during the end of gestation was reported to increase IGF-I concentrations (Averette et al., 1999). Fermented liquid feed during the end of gestation improves colostral mitogenic activity by higher concentrations of growth factors (Demeckova et al., 2002). Supplementation of daidzen during the last 30 days of gestation increased GH, IGF-I and testosterone levels in colostrum (Gen Tao et al., 1999). **Cytokines**, such as IL-4, IL-6, IL-10, IL-12 and IFN-γ have the highest concentrations in colostrum and decline as lactation progresses (Nguyen et al., 2007). **Lipase** and **ribonuclease** acitivity in sow milk was reported by Chandan et al. (1968). Colostrum contains also **protease inhibitors** in order to prevent hydrolysis of Ig and growth factors (Zou et al., 2003). Also **trypsin inhibitor** (Jensen, 1978) have been identified in sow colostrum. **Lysozyme** activity was reported by Krakowski et al. (2002). **Lactoferrin**, **transferrin** (Wagstrom et al., 2000) and **ceruloplasmin** are also supplied by colostrum (Cerveza et al., 2000).

3. IMPORTANCE OF COLOSTRUM

3.1. Introduction

It is well established that insufficient colostrum intake is a major cause of preweaning piglet mortality (Edwards, 2002; Le Dividich et al., 2005; Decaluwé et al. 2014). Devillers et al. (2011) observed a preweaning mortality rate of 43.4% in piglets with a colostrum intake lower than 200 g, whereas this rate was 7.1% with a higher colostrum intake (**Figure 5**). Furthermore, colostrum intake is positively related with weight at weaning and/or at six weeks of age (Devillers et al., 2011; Decaluwé et al., 2014; Ferrari et al., 2014; Vallet et al., 2015). If colostrum intake was above 290 g per pig, weight at six weeks of age was 2 kg heavier in the study by Devillers et al. (2011; **Figure 6**). In addition to these short-term effects, long-term effects of colostrum intake on mortality and performance are presumed (Le Dividich et al., 2005; Devillers et al., 2011; Quesnel et al., 2012; Decaluwé et al., 2014). However, studies investigating such long-term effects of colostrum intake are lacking. Especially studies in commercial pig herds are scarce as most trials on colostrum in pigs were conducted under experimental conditions or in one single herd. Beside mortality and performance, colostrum intake is also associated with gastro-intestinal (e.g. Xu et al., 2000), reproductive (*e.g.* Vallet et al., 2015) and brain (*e.g.* Pierzynowski et al., 2014) development.

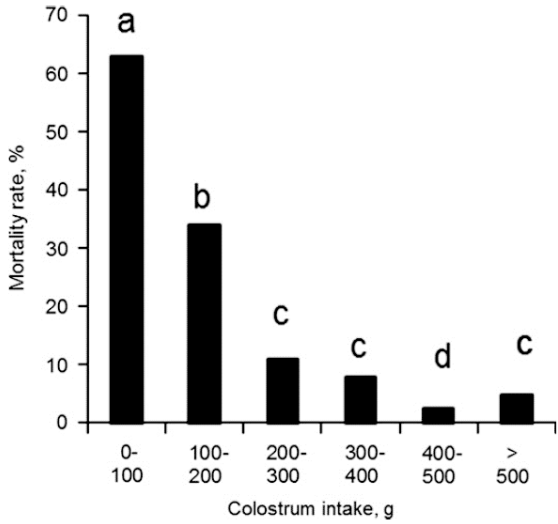

Figure 5. *Relationship between colostrum intake and piglet preweaning mortality (adapted from Devillers et al., 2011; Quesnel et al., 2012).*

The positive relationship between piglets' colostrum intake and survival and performance can be associated with the supply of energy, maternal immunity and bio-active compounds by colostrum. During the first days of life, sufficient energy supply is crucial for piglet survival as piglets' energy demands at birth are maximal (Mellor and Cockburn, 1986; Le Dividich et al., 1994) compared to their reserves (Le Dividich et al., 2005; Theil et al., 2014b). Colostrum, especially colostral fat, is an efficient energy source for neonatal piglets (Le Dividich et al., 1994; Herpin et al., 2002). Beyond the neonatal period, the supply of maternal immunity and bioactive compounds by colostrum is relatively more important than the colostral energy supply (Varley et al., 1986; Xu et al. 2000: Le Dividich et al., 2005).

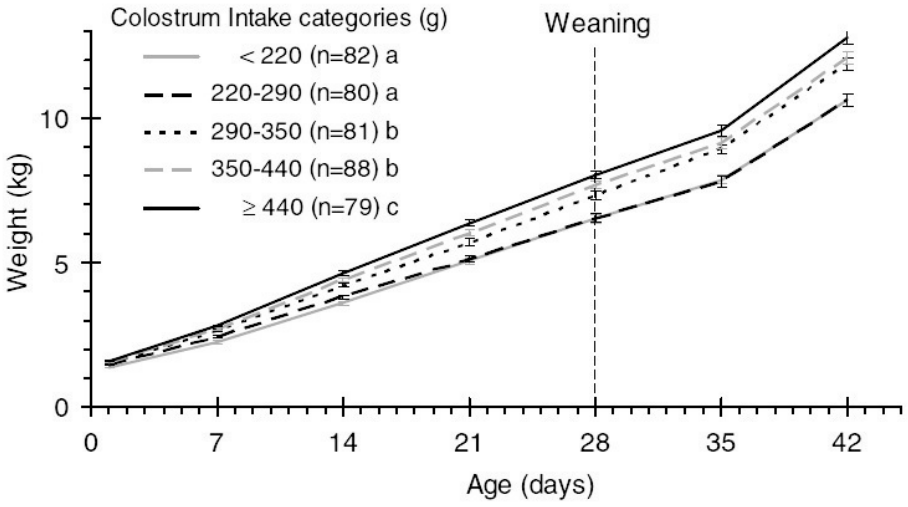

Figure 6. *Relationship between colostrum intake and weight at 6 weeks of age (adapted from Devillers et al., 2011).*

Le Dividich et al. (2005) stated that for optimal preweaning survival, piglets must consume at least 160 g colostrum/kg birth weight. Devillers et al. (2011) recommended a minimum colostrum intake of 200 g. This was also recommended by Quesnel et al. (2012), who advised a minimum colostrum intake of 200 g for sufficient preweaning survival, passive immunity and slight weight gain, and 250 g colostrum intake to achieve good health and lifetime growth performance. Ferrari et al. (2014) reported that survival rate increased when colostrum intake reached 200 or 250 g in intermediate versus low birth weight piglets, respectively. Hence, the minimum amount of colostrum for piglets' survival may depend on birth weight.

3.2. Nutritional importance

In pigs, energy demands are maximal at birth. During the first day of life, a one-kg-piglet requires theoretically at least 900-950 kJ NE (Le Dividich et al., 2005). Small piglets have higher energy demands per kg of birth weight because of their higher surface-to-volume ratio (Noblet and Etienne, 1987). In neonatal piglets, energy is required for growth and maintenance, which includes physical activity and to a great extent thermoregulation (Herpin et al., 2002; Le Dividich et al., 2005).

The energy requirements of neonatal pigs have to be met by body reserves and by colostrum intake. Body reserves can be subdivided into glycogen, protein and fat reserves. Glycogen reserves average 30-38 g per kg birth weight and are deposited during the last month of gestation (Le Dividich et al., 1994; 2005, Theil et al., 2014b). Glycogen reserves are rapidly depleted. During the first 12 h of life, liver and muscle glycogen is decreased with 75 and 41%, respectively (Le Dividich et al., 1994; 2005; Theil et al., 2011). Body protein catabolism is low during the neonatal period (Le Dividich et al., 1994) and the total amount of fat in pigs is very low as it averages 10-20 g/kg. Furthermore, a large proportion (45%) is structural fat and hence, not available for mobilization (Le Dividich et al., 2005). Altogether, energy from glycogen and fat averages 420 kJ/kg birth weight, which is insufficient to cover the energy demands. Therefore, energy supplied by colostrum is crucial to meet the high energy requirements at birth (Le Dividich et al., 2005; Theil et al., 2014b). The gross energy content averages 260 to 346 kJ per 100 g of colostrum (Theil et al., 2014b). Fat is the main source of colostral energy (40 – 60%) (Le Dividich et al., 2005). Colostrum is very digestible and well utilized (Noblet and Etienne, 1987; Le Dividich et al., 1994). The ratio of ME/GE of colostrum averages 93%. The efficiency of ME towards total energy and protein energy averages 91 and 90%, respectively (Le Dividich et al., 1994).

Early and sufficient energy supply is of utmost importance for neonatal survival (Edwards, 2002; Le Dividich et al., 2005; Theil et al., 2014b). As colostrum is the sole external energy source, colostrum is a major determinant regarding (early) preweaning mortality (Le Dividich et al., 2005; Devillers et al., 2011; Decaluwé et al. 2014).

3.3. Immunological importance

At birth, piglets are immunologically underdeveloped due to the lack of antigen exposure across the multilayered placenta and because of underdevelopment of the immune system *per se*. Although, most components of the immune system are present at birth, it takes several weeks before the immune system becomes fully functional (Gaskins, 1998; Bianchi et al., 1999). Due to the epitheliochorial nature of the placenta in pigs, immunoglobulins can fairly not pass from sows' to piglets' circulation (Rooke and Bland, 2002). Hence, piglets are born hypoglobulinemic and passive immunity must be acquired postnatally by colostrum and milk till piglets' immune system is functional (Schanbacher et al., 1997; Salmon et al., 2009).

During the first 24 to 36 h of life, intact IgG can be taken up from the gut by non-specific pinocytosis into the enterocytes and transferred intact to the bloodstream of the piglets (Payne and Marsh, 1962; Clarke and Hardy, 1971). After this short time interval, there is gut closure, which means there is no more transfer of intact macromolecules to the piglets' circulation. Because of this short time window, the supply of IgG by colostrum is of utmost importance (Rooke and Bland, 2002). Nutrients (e.g. glucose and lactose) are mainly involved in the onset of gut closure in a dose-dependent way (Lecce, 1966; Werhahn et al., 1981). Hence, if piglets have adequate intake of colostral nutrients, IgG is absorbed in a minimum time interval in order to reduce the risk of invasion of pathogens into the piglets' circulation before gut closure (Rooke and Bland, 2002). In contrast to immune cells, colostral antibodies are transferred from the gut into the bloodstream, even if they are from another sow or from another species (Klobasa et al., 1981). Beside immunoglobulins, colostrum also contains leukocytes and other immunological active compounds. Leukocytes migrate to mesenteric lymph nodes and other tissues where they have an immunomodulatory effect (Tuboly et al., 1988; Willams, 1993; Tuboly et al., 2002; Nechvatalova et al., 2011). It is not clear if there is a 'gut closure' for maternal leukocyte absorption as it is the case for colostral antibody absorption (Nechvatalova et al., 2011). In addition to immunoglobulins and immune cells, colostrum is also an important source of immunomodulatory cytokines (Nguyen et al., 2007) and antioxidants. The antioxidant status determines immune responses and is related with selenium and vitamin E (Arthur et al., 2003; Pinelli-Saavedra et al., 2008), which are mainly obtained from colostrum (Mahan et al., 2000).

Colostrum protects piglets against pathogens until they are immunologically active. Moreover, the development towards active immunity is positively related with passive immunity (Damm et al., 2002; Rooke and Bland, 2002; Le Dividich et al., 2005; Devillers et al., 2011; **Figure 7**). Hence, a high level of passive immune transfer indirectly promotes resistance to infections, health, and survival (Varley et al., 1986; Le Dividich et al., 2005; Devillers et al., 2011).

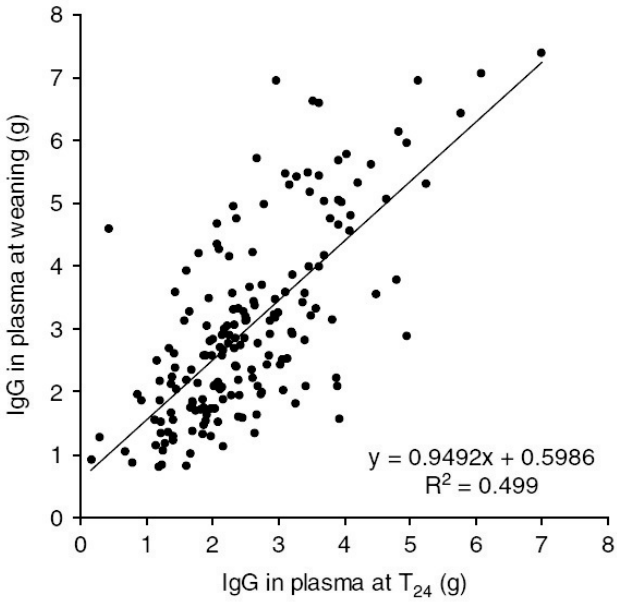

***Figure** 7. Piglet plasma IgG concentration at weaning is positively related with the plasma IgG concentration at 24 h after the onset of farrowing (adapted from Devillers et al., 2011).*

3.4. The lactocrine hypothesis

Lactocrine signaling is defined as the transmission of bioactive factors from mother to offspring as a consequence of nursing (Bartol et al., 2013). The lactocrine hypothesis means that the development of neonatal tissues is affected by milk-born bioactive factors (Rahman et al., 2014).

Gastro-intestinal growth and maturation of its function is affected by the ingestion of colostrum via various growth factors in colostrum and milk, such as epidermal growth factor, insulin-like growth factor-I (IGF-I), IGF II, insulin and transforming growth factor β (Xu et al., 2000). Several milk-born factors stimulate the proliferative capacity of the intestinal epithelium (Slupecka et al., 2010). In addition to the role regarding tissue growth and function maturation, milk-born factors enhance also repair of damaged gastrointestinal mucosa in the suckling pig (Xu et al., 2000). Beside the gastro-intestinal system, growth factors are also involved in reproduction, as low colostrum intake was associated with increased age at puberty, reduced number of live-born piglets and reduced preweaning growth (Vallet et al., 2015). It has been shown that nursing supports endometrial (Miller et al., 2013) and neonatal testicular development (Rahman et al., 2014). Furthermore, Pierzynowskii et al. (2014) reported that colostrum stimulates brain protein synthesis and development.

4. COLOSTRUM PRODUCTION AND INTAKE

4.1. Measurement

Despite the importance of colostrum in the pig, only few studies have been conducted on colostrum because of the challenge to measure colostrum intake in pigs. In contrast with cows, sows' colostrum yield cannot be measured by milking, but must be measured by the intake of colostrum by her piglets (Farmer et al., 2006). Different measurement methods were developed to estimate the intake of colostrum by piglets.

Deuterium dilution method

The deuterium dilution method is considered as the golden standard to estimate precisely and accurately colostrum intake by piglets (Theil et al., 2002; Farmer et al., 2006; 2007; 2014a). This method is based on the estimation of body water turn-over (Dove and Freer, 1979). A marker, such as deuterium oxide (Prawirodigdo et al., 1990), is injected immediately after birth. One hour after injection, a first blood sample is taken to determine the initial concentration of piglets' deuterium oxide. A second blood sample, collected at 24 h after birth, is taken to determine its final concentration. Between first and second blood sampling the marker is diluted by colostrum intake, water supply by digestive, respiratory or metabolic pathways. In order to calculate colostrum intake, the amount of water originating from other sources than colostrum must be taken into account (Dove and Freer, 1979; Coward et al., 1982; Devillers et al., 2004b; Theil et al., 2002). Although piglets can be left with the sows, this method requires piglet blood sampling, which may impact piglets' vitality, metabolism and their colostrum intake as well as their welfare. In conclusion, this method is quite precise, but its intensive nature and expensive chemical analyses makes it difficult to apply it on a large scale (Farmer et al., 2006).

Weight-based methods

Weight gain during the first day of life is commonly used to evaluate colostrum intake. In fact, 86 to 88% of the variance in piglets' weight gains on the first day of life can be attributed to colostrum intake (Le Dividich et al., 2005). Also the weight gain during nursing can be used to measure colostrum intake, which is called the weigh-suckle-weigh method (Barber et

al., 1955). However, faecal, urinary or metabolic weight losses must be taken into account (Pettigrew et al., 1984). This method is widely used to evaluate milk yield, but is not fully suitable to measure colostrum intake. Piglets are separated from the sow between two nursings, which might stress the piglets as well as the sows. Hence, the natural way of sows' colostrum production and piglets' colostrum intake is disturbed (Pettigrew et al., 1984). Furthermore, this method requires a lot of labor regarding animal handling and weighing. In conclusion, the weigh-suckle-weigh method is not considered to be the most appropriate way to measure colostrum intake on a large scale or under commercial conditions (Farmer et al., 2006).

Modellization methods

Devillers et al. (2004b) developed an equation to estimate colostrum intake in 33 bottle-fed piglets, based on birth weight (BWb, kg), weight at 17 to 24 h of age (BW_{24}, kg), time between birth and first suckling (t_{FS}, min) and time elapsed from first suckling to time at BW_{24} (t, min). The regression equation is as follows: $-217.4 + 0.217 \times t + 1\,861\,019 \times BW_{24}/t + BWb \times (54.80 - 1\,861\,019/t) \times (0.9985 - 3.7 \times 10^{-4} t_{FS} + 6.1 \times 10^{-7} \times t_{FS}^2)$. Thereafter, the equation was validated by comparing the colostrum intake estimated by the equation with the colostrum intake measured with the deuterium oxide dilution method, in 12 sow-reared as well as in 12 bottle-fed piglets. The relationship between weight gain and colostrum intake was not different in sow-reared versus bottle-fed piglets and hence, Devillers et al. (2004b) concluded that this equation established in bottle-fed piglets can also be applied in sow-reared piglets.

Theil et al. (2014a) measured colostrum intake in 200 sow-reared piglets by the deuterium oxide dilution technique. Based on these data derived from sow-reared piglets, an equation was developed to predict colostrum intake using birth weight (BW_b, kg), 24-h weight gain (WG, g) and duration of colostrum intake (D, minutes). Duration of colostrum intake is the time between first and second weighing. The equation is the following: $-106 + 2.26\ WG + 200\ BW_b + 0.111\ D - 1414\ WG/D + 0.0182\ WG/BW_b$. Colostrum intake calculated by the equation of Devillers et al. (2004b) was underestimated by 30% in comparison with colostrum intake calculated by the equation of Theil et al. (2014a). Theil et al. (2014a) concluded that the equation developed in bottle-fed piglets by Devillers et al. (2004b) underestimates colostrum intake in sow-reared piglets due to higher physical activity in sow-reared versus bottle-fed piglets. The bottle-fed piglets had a more efficient conversion of ingested nutrients

into growth than the sow-reared piglets, as they don't have to search for available teats or compete with littermates at the udder or perform udder massage (Theil et al., 2014a).

Regardless the differences between both equations, these equations are rather an estimation than an exact measurement of colostrum intake. Hence, both prediction equations must be applied to a large number of animals in order to calculate average production, rather than calculating the exact amount of colostrum produced by one sow (Farmer et al., 2006).

Uptake of immunoglobulins

Because of the epitheliochorial nature of the placenta in sows, immunoglobulins can fairly not cross the placenta and piglets get born hypoglobulinemic. Furthermore, the immune system of newborn piglets is not active till weaning and hence, the sole source of immunoglobulins is colostrum (Le Dividich et al., 2005; Salmon et al., 2009). Therefore, it seems reasonable that the level of IgG in piglets reflects the amount of colostrum acquired by piglets (Vallet et al., 2013). Unfortunately, the association between piglets' IgG level with colostrum intake is not that straightforward, as piglets' IgG level depends not only on the amount of colostrum acquired, but also on the level of IgG in colostrum, on the amount of IgG ingested and absorbed from the gut into the piglets' circulation and on gut closure (Jensen et al., 2001; Rooke and Bland, 2002).

First, the concentration of IgG in colostrum varies greatly among sows (Klobasa and Butler, 1987). Moreover, within a sow, the level of IgG decreases fast and steeply during parturition (**Figure 4**; Quesnel, 2011; Kielland et al., 2015). Hence, first-born piglets have the opportunity to consume colostrum higher in IgG compared to late-born piglets having access to colostrum which IgG content is lower than at the start of the parturition (Kielland et al., 2015). Gut closure depends on the amount of nutrients ingested (Lecce, 1966; Werhahn et al., 1981), and IgG absorption through the intestinal barrier is limited (Jensen et al., 2001). Plasma IgG levels reached a plateau when colostrum intake was higher than 200-250 g (Devillers et al., 2011; **Figure 8**).

Furthermore, the importance of colostrum to newborn piglets is mainly attributed to the supply of energy, rather than the supply of immunoglobulins (Varley et al., 1986; Xu et al. 2000: Le Dividich et al., 2005). Hence, to determine thresholds on the required amount of colostrum intake regarding preweaning performance and survival, colostrum intake should be estimated rather than IgG uptake (Decaluwé et al., 2014b).

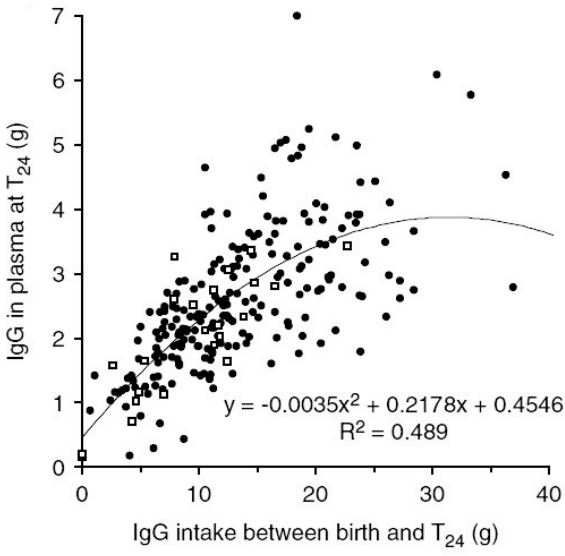

Figure 8. *The estimated amount of IgG ingested with colostrum is related with the estimated amount of IgG present in plasma and suggest a plateau starting around 15 g of ingested IgG (adapted from Devillers et al., 2011).*

4.2. Factors determining and measures improving colostrum production and intake

Colostrum yield

The main characteristic about colostrum yield is its variability among sows. Colostrum yield estimated by Devillers et al. (2004b) averages 3.3-3.7 kg and ranges from 1.5 to 6.0 kg (n = 128 sows) (Devillers et al., 2007; Foisnet et al., 2010a; Quesnel, 2011). Colostrum yield estimated by Theil et al. (2014a) averages 5.9 ± 0.1 kg with a range from 2.7 to 8.5 kg (n = 126 sows) (Theil et al., 2014b; Vadmand et al., 2015). Previous studies suggested that approximately 30% of sows produce insufficient colostrum for their litter (Foisnet et al., 2010a; Quesnel et al., 2012; Decaluwé et al., 2013). Some factors and measures have been considered to unravel this high variability and to improve colostrum yield.

Sow factors

To our knowledge, there is no information whether or not colostrum yield is influenced by genetics in sows. As dairy cows and ewes are reported to produce more colostrum than beef cows and ewes (Pattinson and Thomas, 2004; Godden, 2008), studies investigating colostrum production by different sow breeds are warranted to know whether or not colostrum production differs among sow breeds.

Regarding parity, some studies reported no influence on colostrum yield (Le Dividich et al., 2005; Quesnel, 2011), whereas Devillers et al. (2007) observed a tendency of higher colostrum yield in second and third parity versus other parities. Decaluwé et al. (2013) reported a significant higher colostrum yield in first to third parity versus older sows.

The number of functional teats was observed to be not associated with colostrum yield (Quesnel, 2011). Also no associations between body weight and back fat thickness one week before farrowing and colostrum yield were found (Devillers et al., 20047; Quesnel, 2011), but back fat loss at the end of gestation was found to be negatively associated with colostrum yield. An extra loss of one mm back fat between day 85 and day 109 of gestation was associated with a decrease in colostrum yield of 113 g (Decaluwé et al., 2013). Regarding body protein use before farrowing, a negative as well as a positive association with colostrum yield was reported, probably because most sows were catabolic in the study of Decaluwé et al. (2013) versus anabolic in the study of Loisel et al. (2014).

Gestation length was negatively related with colostrum yield according to Devillers et al. (2007). According to Decaluwé et al. (2013), gestation length was positively related with colostrum yield, probably because of decreased piglet vitality in earlier parturitions. Other studies did not observe a relation between gestation length and colostrum yield (Quesnel, 2011). It is hard to find out whether gestation length and colostrum yield are related, as most studies performed parturition induction (Devillers et al., 2007, 2011; Quesnel, 2011). To investigate the effect of gestation length on colostrum yield, studies should be preferably conducted in sows that farrow naturally to avoid confounding by parturition induction.

Litter factors

In contrast to milk production (Hurley, 2001), litter size is shown to be not related with colostrum production in several studies (Devillers et al., 2007; Foisnet et al., 2010a; Quesnel, 2011; Decaluwé et al., 2014a; **Figure 9**). Also litter weight was not related with colostrum yield (Le Dividich et al., 2005; Farmer and Quesnel, 2009; Foisnet et al., 2010a; Quesnel, 2011), except the study by Devillers et al. (2005), which observed a higher colostrum yield in sows with heavier litters at birth. Colostrum yield was shown to be negatively related with litter heterogeneity (Devillers et al., 2007; Quesnel, 2011), which is consistent with the observation that greater litter heterogeneity results in poorer growth and higher piglet mortality (Milligan et al., 2002; Quiniou et al., 2002).

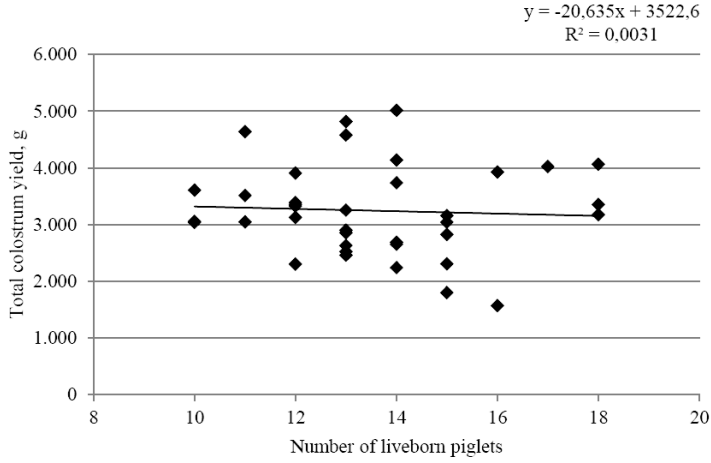

Figure 9. *Total colostrum yield is not associated with the number of live-born piglets (adapted from Decaluwé et al., 2014b)*

Management factors

Parturition induction on day 113 of gestation was found to not affect colostrum yield in sows, however some transient hormonal changes and alterations in colostrum composition occurred shortly after the injection of alfaprostol (Foisnet et al., 2011). Unlike this, Devillers et al. (2007) reported a lower colostrum yield in induced versus naturally farrowing sows. However, this negative association can be confounded by gestation length as only sows with a minimum gestation length of 114 days were induced.

The duration of parturition was shown to be not related with colostrum yield (Devillers et al., 2007: Foisnet et al., 2010a; Quesnel, 2011), whereas stillbirth was found to be negatively related with colostrum yield, probably because of hormonal imbalances in late pregnancy affecting the farrowing process as well as the production of colostrum (Quesnel, 2011). The influence of birth assistance, such as the use of oxytocin during farrowing and manual birth assistance, on colostrum yield has so far not yet been investigated, but would be of great interest to evaluate.

A noisy environment results in lower nursing frequency by compromising sounds of other sows nursing and by disturbing the communication between the sow and her offspring (Algers and Jensen, 1991; Nakamura et al., 1995). Therefore, noisy environment (*e.g.* fan noise at 85dB) might be related with less colostrum ejection (Fraser, 1984) and lower colostrum and milk yield (Algers and Jensen, 1991; Auldist et al., 2000; Farmer and Quesnel, 2009).

Metabolic, nutritional and hormonal factors

Most studies investigated the impact of nutrition and nutritional interventions on colostrum composition, rather than on colostrum yield. Nutrition could affect colostrum production by affecting mammary gland development and/or affecting the metabolic and endocrine pathway of colostrum secretion in late gestation (Farmer and Quesnel, 2009). Overfeeding during gestation gives excessive fat deposition in sows, which compromises mammogenesis (Farmer and Sorensen, 2001). According to Decaluwé et al. (2013), mobilization of body reserves during late gestation is associated with lower colostrum yield, probably by compromising mammogenesis or by altering sows' insulin sensitivity. During late gestation, all sows develop insulin resistance (Père et al. 2000). This is needed to direct glucose to the mammary gland (Père and Etienne, 2007), but it is only warranted to some degree as sows with low colostrum yield had higher glucose concentrations one week before farrowing than sows with

high colostrum yield (Foisnet et al., 2010a). Also a decreased glucose tolerance at day 104 of gestation was associated with higher piglet mortality (Kemp et al., 1996). Supplementation with β-hydroxy β-methyl butyrate during the end of gestation and lactation improved colostrum yield by altering the intermediary metabolism of sows (Flummer and Theil, 2012). In cows, dietary conjugated linoleic acid affects the metabolism of the mammary gland and increases milk yield (Zheng et al., 2005), however, in sows, supplementation of conjugated linoleic acid in late gestation tended to decrease colostrum production (Krogh et al., 2012). By altering peripartum concentrations of lactogenic hormones, different strategies were supposed to affect colostrum yield. Nevertheless, parturition induction (Foisnet et al., 2011), high fibre during end of gestation (Loisel et al., 2013) or supplementing silymarin (Loisel et al., 2014) were observed to not alter hormonal concentrations of progesterone, prolactin, estrogen or cortisol around farrowing and hence, these strategies did neither affect colostrum yield. Diets high in fibre during the end of gestation did not improve colostrum yield, but the colostrum intake by low birth weight piglets was increased (Loisel et al., 2013). Theil et al. (2014a) observed a higher colostrum intake in piglets from sows fed with sugarbeet pulp or pectine residue versus potato pulp or low fiber diet during the end of gestation.

Colostrum intake

Colostrum intake substantially varies across piglets. In the study of Devillers et al., (2007) colostrum intake averaged 300 ± 7 g and ranged from 0 to 710 g (n = 489 piglets). Between litters, the coefficient of variation of colostrum intake averaged 30%, but even within litters, colostrum intake is highly variable as the coefficient of variation of colostrum intake within litters averaged 40% and ranged from 15 to 110% (Le Dividich et al., 2005).

Genotype

To the best of our knowledge, the influence of breed on colostrum intake has not been investigated so far. Yet, it would be highly interesting to study this effect as colostrum management might be optimized by using a breed-specific approach.

Birth weight

As shown in the the regression equations by Devillers et al. (2004b) and Theil et al. (2014a) to estimate colostrum intake, birth weight largely determines colostrum intake. However, Devillers et al. (2007) observed a higher impact of birth weight (colostrum increases by 28 g if birth weight increases by 100 g) than derived from the equation itself (colostrum increases by 7 g if birth weight increases by 100 g). Furthermore, colostrum intake per kg birth weight depends also on birth weight, which confirms the advantage of heavy littermates. Altogether, the role of birth weight on colostrum intake is established despite the fact that birth weight is used to estimate colostrum intake by Devillers et al. (2004b) or Theil et al. (2014a). The positive association between birth weight and colostrum intake (Tuscherer et al., 2000; Le Dividich et al., 2005; Devillers et al., 2007) is due to the fact that low birth weight piglets are less able to compete. First, they are smaller (Rooke and Bland, 2002). Secondly, they have higher relative energy requirements due to their higher surface to body mass ratio and are therefore more prone to cold stress (Noblet and Etienne, 1987; Herpin et al., 2002). Energy supplementation to low birth weight piglets may compensate partially for these higher relative energy demands and hence, favor colostrum intake in low birth weight piglets by rendering them more competitive at the udder. However, studies evaluating the effect of management practices on colostrum intake are scarce and peer-reviewed scientific studies regarding commercial energy supplements to neonatal piglets are scarce. Thirdly, low birth weight piglets differ physiologically from their littermates (Rooke et al., 2001; Michiels et al., 2013)

and finally, they lack the ability to extract successfully colostrum and milk from the teats (Milligan et al., 2001; Le Dividich et al., 2005; Devillers et al., 2007).

A lot of nutritional measures in the sow, such as increase in feed intake (Bee, 2004; Quiniou et al., 2005; Lawlor et al., 2007; Cerisuelo et al., 2009) or specific supplements (Van den Brand et al., 2006; Cools et al., 2011; Quesnel et al. 2014) were investigated to improve birth weight, however mostly without success. Selection towards larger litter size resulted in lower piglet birth weight and litter homogeneity (Milligan et al., 2002; Quiniou et al., 2002; Quesnel et al., 2008). Hence, in future, selection procedures should take into account the negative effect of reduced birth weight on colostrum intake and hence, further decrease in birth weight and piglet heterogeneity should be stopped (Wolf et al., 2008).

Vitality

Vitality is shown to influence the acquisition of colostrum (Devillers et al., 2007; Quesnel et al., 2012). The interval between birth and first suckling is an important indicator of piglet vitality at birth (Herpin et al., 1996; Tuchscherer et al., 2000; Baxter et al., 2008). Foisnet et al. (2010a) observed a negative correlation between this interval and litter weight gain on the first day of life. Vitality must be optimized in order to ensure piglets' ability to look up the udder and to compete and suckle a teat.

First, vitality should be optimized by preventing intra-partum asphyxia through reduction of farrowing duration (Herpin et al., 1996; Alonso-Spilsbury et al., 2007). Risk factors for prolonged duration of farrowing are confinement stress, high back fat levels at farrowing and constipation (Oliviero et al., 2010). Also farrowing supervision, such as manual birth assistance or oxytocin injection, can be helpful to reduce farrowing duration. However, oxytocin should be used carefully, as oxytocin misuse can cause intrauterine asphyxia, which is associated with stillbirth and compromised vitality (Herpin et al., 1996; Alonso-Spilsbury et al., 2004; Mota-Rojas et al., 2005). Secondly, piglets' vitality can be improved by maternal nutrition, such as higher feed intake during the end of gestation (Quiniou et al., 2005), supplementation with fish oil (Rooke et al., 2001; Tanghe et al., 2013) or algal biomass (Adeleye et al., 2014) or including a high-fiber level (Loisel et al., 2013). Finally, neonatal piglets with compromised vitality should get additional care to improve their suckling ability and survival (Holyoake et al., 1995; Boulot et al., 2008). Neonatal care of (weak) piglets can include the supply of energy-rich pastes (De Vos et al., 2014; Muns et al., 2015) or colostrum

(Holyoake et al., 1995; Muns et al., 2015), placing them under a heat lamp (Andersen et al., 2009; Holyoake et al., 1995) or at the udder (Vasdal et al., 2011) or drying (Andersen et al., 2009; Vasdal et al., 2011).

Birth order

Late-born piglets have less time to consume colostrum compared to their first-born littermates (Devillers et al., 2007) and are also more prone to suffer from impaired vitality through intra-partum hypoxia and hence, decreased suckling capacity (Herpin et al., 1996). Furthermore, late-born piglets have access to colostrum of lower IgG concentration (Klobasa et al., 2004). Therefore, a negative relationship between birth order and colostrum (IgG) intake was assumed to clarify the adverse effect of birth order on postnatal mortality (Cabrera et al., 2012; Charneca et al., 2015), however the relationship between colostrum intake and birth order was not observed by Devillers et al. (2007), Le Dividich et al.(2005) and Quesnel et al.(2012).

Litter size and litter heterogeneity

Litter size has a negative effect on piglets' colostrum intake. For each additional live-born piglet, colostrum availability per piglet decreases with 22 to 42 g (Devillers et al., 2004b) or 11 g (Kielland et al., 2015). Several aspects can explain the negative association between colostrum intake and litter size. First, colostrum yield is independent from litter size (Devillers et al., 2007; Quesnel, 2011). Hence, there is more competition among littermates in large versus small litters (Milligan et al., 2001) and competition at the udder by teat fights disturbs colostrum ejection by the sow (Andersen et al., 2011). Further, large litters imply decreased average piglet birth weight (Akdag et al., 2009; Beaulieu et al., 2010), which has a major role in determining colostrum intake. Finally, in large litters the proportion of low birth weight piglets is increased and hence, competition is emphasized at the expense of low birth weight piglets (Milligan et al., 2002; Quiniou et al., 2002; Quesnel et al., 2008; **Figure 10**). It is of utmost importance in large litters to share the available amount of colostrum optimally across littermates by using proper management strategies (Baxter et al., 2013) such as cross-fostering (Cecchinato et al., 2008) or split suckling (Donovan and Dritz, 2000). In order to decrease within-litter heterogeneity, dextrose supplementation to the sow around weaning (Van den Brand et al., 2006), reduction of retinol (Antipatis et al., 2008), arginine and; or

glutamine (Quesnel et al., 2014; Li et al., 2015) during gestation might be advisable. Regarding sow body condition, litter heterogeneity was found to be positively related with back fat gain during gestation (Quesnel et al., 2008) and with back fat loss during previous lactation (Wientjes et al., 2013). Besides piglet management and sow nutritional measures, genetic selection on litter uniformity is feasible (Damgaard et al., 2003; Wolf et al., 2008; Kapell et al., 2011).

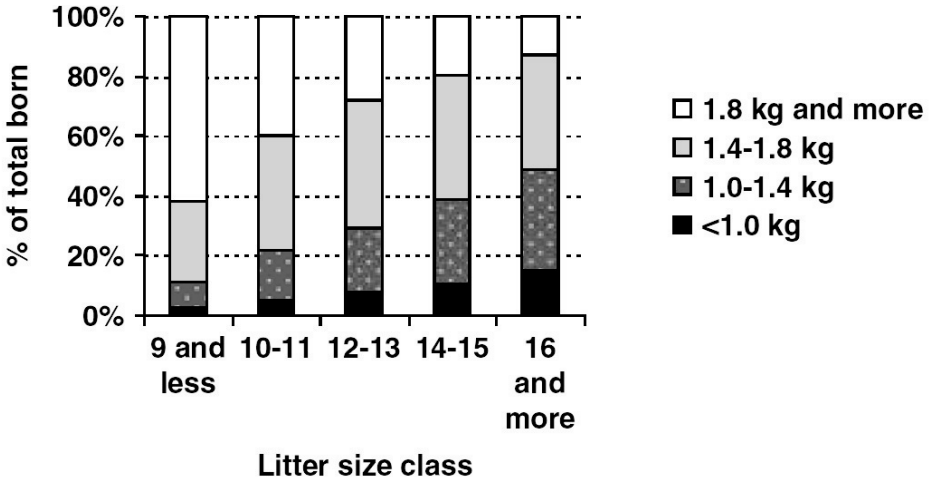

Figure 10. *Increase in litter size is associated with a higher proportion of small piglets (< 1.0 kg) (adapted from Quesnel et al., 2008).*

5. PREWEANING PERFORMANCE AND MORTALITY

The number of piglets born per sow per year has been substantially improved by the introduction of high-prolific sow breeds (Beaulieu et al., 2010; Rutherford et al., 2013). However, also preweaning mortality has increased. It averages 12.9% in the European Union (Interpigs report, 2014) and hence, remains a major economic and welfare problem in swine production. The most critical period is the first 72 h of life (Tuchscherer et al., 2000). Infectious as well as non-infectious causes of preweaning mortality can be distinguished, however emphasis is given on non-infectious causes by this introduction. It is generally accepted that crushing is the major cause of preweaning mortality, with starvation and hypothermia as underlying causes. Piglet survival is considered as the outcome of complex interactions between piglet, sow and environmental factors (Edwards, 2002; Muns et al., 2016; **Figure 11**). Factors involved in preweaning mortality are mostly also associated with poor preweaning performance (Panzardi et al., 2013).

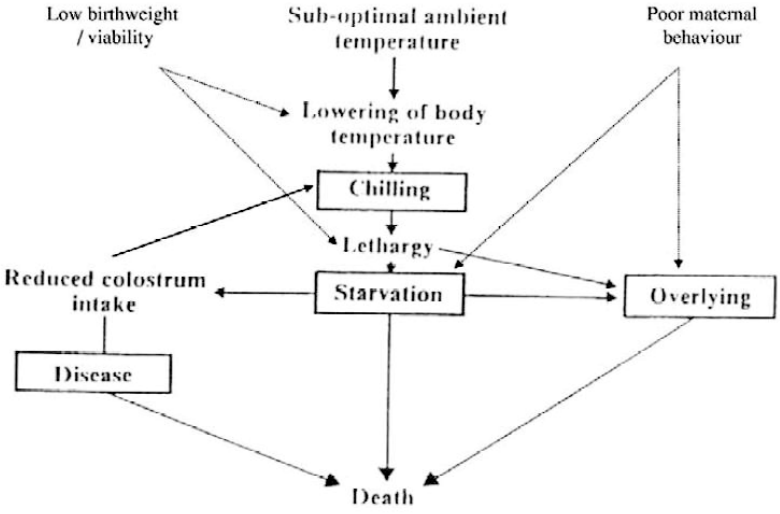

Figure 11. *Sow, piglet and environmental interactions on crushing, starvation and hypothermia (adapted from Edwards, 2002).*

5.1. Piglet factors

Birth weight is considered to be the main piglet factor determining preweaning mortality (Milligan et al., 2002; Quiniou et al., 2002; Baxter et al., 2008; Panzardi et al., 2013). Low birth weight piglets are more prone to suffer from hypothermia (Herpin et al., 2002) and hypoxia (Herpin et al., 1996) and, as mentioned before, have a lower colostrum intake. Birth weight determines also weaning weight (Milligan et al., 2002; Gondret et al., 2005; Rehfeldt et al., 2008; Panzardi et al., 2013; Ferrari et al., 2014). Quiniou et al. (2002) observed that each additional 100 g of birth weight for pigs weighing 1 kg or 2 kg at birth induces an increase of the weaning weight by 400 or 200 g, respectively (**Figure 12**). Large piglets are directly and indirectly advantaged to obtain a teat and to simulate and drain their teats more effectively (Milligan et al., 2002). Due to the higher colostrum and milk intake in large piglets, the initial differences in birth weight might remain, or even increase throughout lactation. This explains the positive relationship beween variation in birth and weaning weight observed by Panzardi et al. (2013).

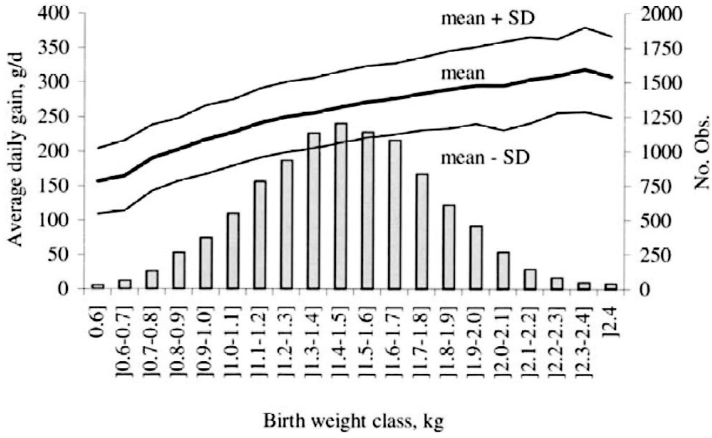

Figure 12. *Evolution of preweaning daily weight gain (bold line) with birth weight classs and number of piglets weaned per birth weight class (bar) (adapted from Quiniou et al., 2002).*

5.2. Sow factors

As described earlier, production of colostrum affects preweaning mortality and performance. Alonso-Spilsbury et al. (2007) stated that 6 to 17% of all preweaning mortality in commercial pig farms can be attributed to lactation failure.

Parity was shown to be positively (Muns et al., 2015), negatively (Li et al., 2012) or not (Knol et al., 2002; Carney-Hinkle et al., 2013) related with preweaning mortality. Parity was found to be positively related with the variation in weaning weight (Milligan et al., 2002). This might be linked with reduced and more variable function and accessibility of teats in older sows (English et al., 1977; Vasdal and Andersen, 2012) .

5.3. Environmental factors

A low ambient temperature was found to increase preweaning mortality firstly because colostrum intake decreases during cold exposure (Pedersen et al., 2013) and secondly because piglets are at more risk to be crushed as they stay close to the udder in search for a heat source (Shankar et al., 2009). Some studies have shown that preweaning mortality due to crushing was lower in conventional farrowing crates versus different loose-housing systems (Kilbride et al., 2010; Baxter et al., 2012). Farrowing supervision may not only reduce stillbirths, but might also reduce piglet preweaning mortality (Holyoake et al., 1995; Vanderhaeghe et al., 2013). There are many management strategies to improve preweaning survival and performance by providing additional piglet care (*e.g.* colostrum, energy and oxygen administration, drying and placing piglets under a heat lamp or at the udder, split suckling or cross-fostering). However, most studies on piglet-care are performed under experimental conditions or evaluate a combination of strategies, which compromise the proper evaluation of each strategy separately.

6. REFERENCES CITED

- Akdag, F., S. Arslan, and H. Dimir. 2009. The effect of parity and litter size on birth weight and the effect of birth weight variations on weaning weight and preweaning survival in piglet. J. Anim. Vet. Adv. 8 (11): 2133-2138.
- Al-Matubsi H.Y., G. Bervanakis, S.M. Tritton, R.G. Campbell, and R.J. Fairclough. 1998. Influence of dietary protein of diets given in late gestation and during lactation on protein content and oestrogen concentrations in the colostrum and milk of gilts. Anim. Sci. 67: 139-145.
- Algers, B., and P. Jensen. 1985. Communication during suckling gin the domestic pig. Effects of continuous noise. Appl. Anim. Behav. Sci. 14: 49-61.
- Alonso-Spilsbury M., D. Mota-Rojas, J. Martinez-Burnes, E. Arch, A. Lopez, R. Ramirez-Necoechea, A. Olmos, and M.E. Trujillo. 2004. Use of oxytocin in penned sows and its effect on fetal intra-partum asphyxia. Anim. Reprod. Sci. 84:157-167.
- Alonso-Spilsbury, M, R. Ramírez-Necoechea, M. González-Lozano, D. Mota-Rojas, and M.E. Trujillo-Ortega. 2007. Piglet survival in early lactation: a review. J. Anim. Vet. Adv. 6:76-86.
- Andersen, I.L, I.A. Haukvik, and K.E. Bøe. 2009. Drying and warming immediately after birth may reduce piglet mortality in loose-housed sows. Animal 3, 592-597.
- Andersen, I.L., E. Naevdal, and K.E. Bøe. 2011. Maternal investment, sibling competition, and offspring survival with increasing litter size and parity in pigs. Behav. Ecol. Sociobiol. 65:1159-1167.
- Antipatis, C., A.M. Finch, and C.J. Ashworth. 2008. Effect of controlled alterations in maternal dietary retinol on foetal and neonatal retinol status and pregnancy outcome in pigs. Livest. Sci. 118: 247-254.
- Arthur, J.R., R.C. Mckenzie, and G.J. Beckett. 2003. Selenium in the immune system. Journal of Nutr. 133: 1457-1459.
- Auldist, D.E., D. Carlson, L. Morrish, C.M. Wakeford, and R.H. King. 2000. The influence of suckling interval on milk production of sows. J. Anim. Sci. 78: 2026-2031.
- Averette, L.A., J. Odle, M.H. Monaco, and S.M. Donovan. 1999. Dietary fat during pregnancy and lactation increases milk fat and insulin-like growth factor I concentrations and improves neonatl growth rates in swine. J. Nutr. 129: 2123-2129.

- Bandrick, M., M. Pieters, C. Pijoan, S.K. Baidoo, and T.W. Mollitor. 2011. Effect of cross-fostering on transfer of maternal immunity to Mycoplasma hyopneumoniae to piglets. Veterinary record 168: 100-107.
- Barber, R.S., R. Braude, and K.G. Mitchell. 1955. Studies on milk production of Large White pigs. J. Agric. Sci. Cambridge 46: 97-118.
- Barrington, G.M., T.B. McFadden, M.T. Huyler, and T.E. Besser. 2001. Regulation of colostrogenesis in cattle. Livest. Prod. Sci. 70: 95-104.
- Bartol, F.F., A.A. Wiley, D.J. Miller, A.J. Silva, K.E. Roberts, M.L.P. Davolt, J.C. Chen, A.-L. Frankshun, M.E. Camp, K.M. Rahman, J.L. Vallet, and C.A. Bagnell. 2013. Lactation biology symposium: lactocrine signaling and developmental programming. J. Anim. Sci. 91:696-705.
- Bate, L.A., and R.R. Hacker. 1985. Influence of environmental temperature during late gestation and soon after birth on IgG absorption by newborn piglets. Can. J. Anim. Sci. 65: 87-93.
- Baxter, E.M., S. Jarvis, R.B. D'Eath, D.W. Ross, S.K. Robson, M. Farish, I.M. Nevvison, A.B. Lawrence, and S.A. Edwards. 2008. Investigating the behavioural and physiological indicators of neonatal survival in pigs. Theriogenology 69:773-783.
- Baxter, E.M., A.B. Lawrence, and S.A. Edwards. 2012. Alternatve farrowing accommodation: welfare and economic aspects of existing farrowing and lactation systems for pigs. Animal 6: 96-117.
- Baxter, E.M., K.M.D. Rutherford, R.B. D'Eath, G. Arnott, S.P. Turner, P. Sandøe, V.A. Moustsen, F. Thorup, S.A. Edwards, and A.B. Lawrence. 2013. The welfare implications of large litter size in the domestic pig II: management factors. Animal Welfare 22: 219-238.
- Beaulieu, A.D., J.L. Aalhus, N.H. Williams, J.F. Patience (2010). Impact of piglet birth weight, birth order, and litter size on subsequent growth performance, carcass quality, muscle composition, and eating quality of pork. J. Anim. Sci. 88: 2767-2778.
- Bianchi, A.T.J., J.W. Scholten, H.W.M. Moonen-Leusen, and W.J.A. Boersma. 1999. Development of the natural response of immunoglobulin secreting cells in the pig as a function of organ, age and housing. Dev. Comp. Immunol. 23: 511-520.
- Bland, I.M., and J.A. Rooke. 1998. Effects of sow, udder section and time on colostrum immunoglobulin G (IgG) concentrations and piglet colostrum intake. In Proceedings of the British Society of Animal Science, p. 158.

- Bland, I.M., J.A. Rooke, A.G. Sinclair, V.C. Bland, and S.A. Edwards. 2001. Effect of supplementing the maternal diet with vitamins and vaccinating the sow on immunoglobulin G concentrations in piglet plasma. Proc. Nutr. Soc. 60: 72a.
- Bontempo, V., D. Siannimanico, G. Pastorell, R. Rossi, F. Rosi, and C. Corino. 2004. Dietary conjugated linoleic acid positively affects immunologic variables in lactating sows and piglets. J. Nutr. 134: 817-824.
- Boulot, S., H. Quesnel, and N. Quiniou. 2008. Management of high prolificacy in French herds: can we alleviate side effects on piglet survival? In: Ball, R.O. (Ed.), Advances in Pork Production, Proceedings of the 2008 Banff Pork Seminar. University of Alberta 19, p. 213-220.
- Bourne, F.J., T.J. Newby, and J.W. Chidlow. 1975. The influence of route of vaccination on the systemic and local immune response in the pig. Res. Vet. Sci. 18: 244-248.
- Bourne, F.J., and J. Curtis. 1973. The transfer of immunoglobulins IgG, IgA and IgM from serum to colostrum and milk in the sow. Immunology 24: 157-162.
- Boyd, R.D., B.D. Moser, E.R. Peo, A.J. Lewis, and R.K. Johnson. 1982. Efffectt of tallow and choline chloride addition to the diet of sows on milk composition, milk yield and preweaning pig performance. J. Anim. Sci. 54: 1-7.
- Cabrera, R.A., X. Lin, J.M. Campbell and J. Odle. 2012. Influence of birth order, birth weight, colostrum and serum immunoglobulin G on neonatal piglet survival. J. Anim. Sci. and Biotech. 3:42.
- Carney-Hinkle, E.E., H. Tran, J.W. Bundy, R. Moreno, P.S. Miller, and T.E. Burkey. 2013. Effect of dam parity on litter performance, transfer of passive immunity, and progeny microbial ecology. J. Anim. Sci. 91: 2885-2893.
- Cecchinato, A., V. Bonfatti, L. Galoo, and P. Carnier. 2008. Survival analysis of preweaning piglet survival in a dry-cured hamproducing crossbred line. J. Anim. Sci. 86: 2486-2495.
- Cerveza, P.J., F. Mehrbod, S.J. Cotton, N. Lomerlli, M.C. Linder, *E.G.* Fonda, and S.J. Wickler. 2000. Milk ceruloplasmin and its expression by mammary gland and liver in pigs. Archives of Biochemistry and Biophysics 373: 451-461.
- Chandan, R.C., R.M. Parry, and K.M. Shahani. 1968. Lysozyme, lipase, and ribonuclease in milk of various species. J. Dairy Sci. 51: 606-607.
- Charneca, R., M.J. Vila-viçosa, P. Infante, J. Nunes, and J. Le Dividich. 2015. Colostrum production nof Alentejano and Large-White x Landrace sows:

consumption, passive immunity and mortality of piglets. Span. J. Agric. Res. 8: 317-325.

- Chung, Y.K., and D.C. Mahan. 1995. Efficacy of various injectable vitamin E forms on sow vitamin E transfer. Korean J. Anim. Sci. 37: 616-622.
- Clarke, R.M., and R.N. Hardy. 1971. Histological changes in the small intestine of the young pig and their relation to macromolecular uptake. J. Anat. 108: 63-77.
- Coffey, M.T.., J.A. Yates, and G.E. Combs. 1987. Effects of feeding sows fat or fructose during late gestation and lactation. J. Anim. Sci. 65: 1249-1256.
- Corino C., G. Pastorelli, F. Rosi, V. Bontempo, and R. Rossi. 2009. Effect of dietary conjugated linoleic acid supplementation in sows on performance and immunoglobulin concentration in piglets. J. Anim. Sci. 87: 2299-2305.
- Coward, W.A., T.J. Cole, H. Gerber, S.B. Robers, and I. Fleet. Waterturnover and thee measurement of milk intake. Pflügers Archive 393: 344-347.
- Csapo, J., T.G. Martin, Z.S. Csapo-Kiss, and Z. Hazas. 1996. Protein, fats, vitamin and mineral concentrations in porcine colostrum and milk from parturition to 60 days. Int. Dairy J. 6: 881-902.
- Damgaard, L.H., L. Rydhmer, and P. Lovendahl. 2003. Genetic parameters for within-litter variation in piglet birth weight and change in within-litter variation in piglet birth weight and change in within-litter variation during suckling. J. Anim. Sci. 81: 604-610.
- Damm, B.I., N.C. Friggens, J. Nielsen, K.L. Ingvarsten and, L.J. Pedersen. 2002. Factors affecting the transfer of porcine parvovirus antibodies from sow to piglets. Journal of Veterinary Medicine. A Physiology, Pathology, Clinical Medicine 49:487-495.
- Decaluwé, R., D. Maes, I. Declerck, A. Cools, B. Wuyts, S. De Smet and G.P.J. Janssens. 2013. Changes in back fat thickness during late gestation predict colostrum yield in sows. Animal 7:1999-2007.
- Decaluwé R., D. Maes, A. Cools, B. Wuyts, S. De Smet, B. Marescau, P.P. De Deyn, and G.P.J. Janssens. 2014a. Effect of peripartal feeding strategy on colostrum yield and composition in sows. J. Anim. Sci. 92: 3557-3567.
- Decaluwé, R., D. Maes, B. Wuyts, A. Cools, S. Piepers, and G.P.J. Janssens. 2014b. Piglets' colostrum intake associates with daily weight gain and survival until weaning. Livest Sci 162:185-192.

- Delouis, C., L.M. Houdebine, and P. Richard. 2001. La lactation. In: La reproduction chez les mammifères et l'homm. C. Thibault, and M.C. Levasseur (Eds). INRA Editions - Ellipses, France, p. 580-609.
- Demeckova, V., D Kelly, P.H. Brooks, and A. Campbell. 2002. Influence of feeding fermented liquid feed on faecal bacterial flora and selected colostrum parameters of lactating sows. Proc. Br. Soc. Anim. Sci. 83.
- Demeckova, V., C.A. Tsourgiannis, and P.H. Brooks. 2003. The effect of fermented liquid feed, fed in late pregnancy, on the protein and immunoglobulin contents of porcine colostrum. 9th Int. Symp. Digest.Physiol. Pigs. Banff, Albera, Canada 2: 87-89.
- Passillé de, A.M., and Rushen, J., 1989. Using early suckling behavior and weight gain to identify piglets at risk. Can. J. Anim. Sci. 69, 535-544.
- Devillers N., C. Farmer, J. Le Dividich, and A. Prunier. 2007. Variability of colostrum yield and colostrum intake in pigs. Animal 1: 1033-1041.
- Devillers, N., C. Farmer, A.M. Mounier, J. Le Dividich, and A. Prunier. 2004a. Hormones, IgG and lactose changes around parturition in plasma, and colostrum or saliva of multiparous sows. Reprod. Nutr. Dev. 44:381-396.
- Devillers, N., J. Le Dividich, and A. Prunier. 2006. Physiologie de la production de colostrum chez la truie. INRA Prod. Anim. 19 (1):29-38.
- Devillers N., J. Le Dividich, and A. Prunier. 2011. Influence of colostrum intake on piglet survival and immunity. Animal 5:1605-1612.
- Devillers, N., van Milgen, J., Prunier, A., Le Dividich, J., 2004b. Estimation of colostrum intake in the neonatal pig. Anim. Sci. 78, 305-313.
- De Vos, M., Che, L., Huygelen, V., Willemen, S., Michiels, J., Van Cruchten, S., Van Ginneken, C., 2014. Nutritional interventions to prevent and rear low-birthweight piglets. J. Anim. Phys.and Nutr. 98, 609-619.
- Donovan, T.S., and S.S. Dritz. 2000. Effect of split nursing on variation in pig growth from birth to weaning. J. Am. Vet. Ass. 217: 79-81.
- Dove, H., and M. Freer 1979. The accurancy of tritiated water turnover rate as an estimate of milk intake in lambs. Austr. J. Agric. Res. 30: 725-739.
- Edwards, S.A. 2002. Perinatal mortality in the pig: environmental or physiological solutions? Livest. Prod. Sci. 78:3-12.

- Ellendorff F., M. Taverne, F. Elsaesser, M.L. Forsling, N. Parvizi, C. Naaktgeboren, and D. Smidt. 1979. Endocrinology of parturition in the pig. Anim. Reprod. Sci. 2:323-334.
- English, P.R., W.J. Smith, and A. Maclean. 1977. The sow: improving her efficiency. Farming Press Ltd, Ipswich, UK.
- Estienne, M.J., A.F. Harper, C.R. Barb, and M.J. Azain. Concentrations of leptin in serum and milk collected from lactating sows differing in body condition. Dom. Anim. End. 19: 275-280.
- Falconer, I.R. 1980. Aspects of the biochemistry, physiology and endocrionology of lactation. Aust. J. Biol. Sci. 33: 71-84.
- Farmer, C. 2001. The role of prolactin for mammogenesis and galactopoiesis in swine. Livest. Prod. Sci. 70: 105-113.
- Farmer, C. and P. Brazeau. 1992. Colostrum and milk composition of sows immunized against somatostatin or its carrier protein. Can. J. Anim. Sci. 87:511-515.
- Farmer, C., P. Charagu, and M.F. Palin. 2007. Influence of genotype on metabolic variables, colostrum and milk composition of primiparous sows. Can. J. Anim. Sci. 88: 511-515.
- Farmer, C., N. Devillers, J.A. Rooke, and J. Le Dividich. 2006. Pig News and Information 27: Review 1-16 or CAB Reviews: Perspectives in Agriculture, Veterinary Science. Nutrition and Natural Resources 1.
- Farmer, C., S.K. Houtz, and D.R. Hagen. 1987. Estrone concentration in sow milk during and after parturition. J. Anim. Sci. 64: 1086-1089.
- Farmer, C., D. Petitclerc, M.T. Srensen, M. Vignola, and J.Y. Dourmad. 2004. Impacts of dietary protein level and feed restriction during prepuberty on mammogenesis in gilts. J. Anim. Sci. 82: 2343-2351.
- Farmer, C. and H. Quesnel, 2009. Nutritional, hormonal and environmental effects on colostrum in sows. J. Anim. Sci. 87:56-64.
- Farmer, C., S. Robert, and J. Rushen. 1998. Bromocryptine given orally to periparturient of lactating sows inhibits milk production. J. Anim. Sci. 76: 750-757.
- Farmer, C, and M.T. Sørensen. 2001. Factors affecting mammary development in gilts. Livest. Prod. Sci. 70: 141-148.
- Ferrari, C.V., P.E. Sbardella, M.L. Bernardi, M.L. Coutinho, I.S. Vaz Jr., I. Wentz, and F.P. Bortolozzo. 2014. Effect of birth weight and colostrum intake on mortality

and performance of piglets after cross-fostering in sows of different parities. Preventive Veterinary Medicine 114: 259-266.

- Flummer, C., and P.K. Theil. 2012. Effect of β-hydroxy β-methyl butyrate supplementation of sows in late gestation and lactation on sow production of colostrum and milk and piglet performance. J. Anim. Sci. 90: 372-374.
- Foisnet, A., C. Farmer, C. David, and H. Quesnel. 2010a. Relationships between colostrum production by primiparous sows and sow physiology around parturition. J. Anim. Sci. 88:1672-1683.
- Foisnet, A., C. Farmer, C. David, and H. Quesnel. 2010b. Altrenogest treatment during late pregnancy did not reduce colostrum yield in primiparous sows. J. Anim. Sci. 88: 1684-1693.
- Foisnet, A., C. Farmer, C. David, and H. Quesnel. 2011. Farrowing induction induces transient alterations in prolactin concentrations and colostrum composition in primiparous sows. J. Anim. Sci. 89:3048-3059.
- Fraser, D. 1984. Some factors influencing the availability of colostrum to piglets. Anim. Prod. 39: 115-123.
- Gallagher, D.P., P.F. Cotter, and D.M. Mulvihill. 1997. Porcine milk proteins: a review. Int. Dairy Journal 7: 99-118.
- Gaskins, H.R. 1998. Immunological development and mucosal defence in the pig intestine. In: Wiseman, J., M.A. Varley and J.P. Chadwick (Eds), Progress in pig science. Nottingham University Press, Nottingham, p81-102.
- Godden, S. 2008. Colostrum management for dairy calves. Vet. Clin. North Am. Food Anim. Pract. 24: 19-39.
- Gondret, F., L. Lefaucheur, I. Louveau, B. Lebret, X. Pichodo, and Y. Le Cozler. 2005. Influence of piglet birth weight on postnatal growth performance, tissue lipogenic capacity and muscle histological traits at market weight. Livest. Prod. Sci. 93: 137-146.
- Gooneratne, A., P.E. Hartmann, I. McCauley, and C.E. Martin. 1979. Control of parturition in the sow using progesterone and prostaglandin. Aust. J. Biol. Sci. 32: 587-595.
- Göransson, L. 1990. The effect of late pregnancy feed allowance on the composition of the sow's colostrum and milk. Acta Vet. Scand. 31: 109-115.
- Gudding, R. 2010. Vaksinasjon av dyr. Scaninavian Veterinary Press, Oslo, Norway.

- Hakansson, J., J. Hakkarainen, and N. Lundeheim. Variation in vitamin E, glutathione peroxidase and retion concentrations in blood plasma of primiparous sows and their piglets, and in viamin E, selenium and retion content in sows' milk. Acta Agriculturae Scandinavica Section A, Anim. Sci. 51: 224-234.
- Hartmann, P.E., and M.A. Holmes. 1989. Sow lactation. In: Barnett J.L., Hennessy D.P. (Eds), manipulationg pig production UU, Australasian pig science association, Werribee, Australia, 72-97.
- Herpin, P., M. Damon, and J. Le Dividich. 2002. Development of thermoregulation and neonatal survival in pigs. Livest. Prod. Sci. 78:25-45.
- Heying, E.K., M. Grahn, K.V. Pixley, T. Rochefor, and S.A. Tanumihardjo. 2013. Hihg-provitamin A carotenoid maize increases hepatic vitamin A reserves of offspring in a vitamin A-depleted sow-piglet model during lactation. J. Nutr. 143: 1141-1146.
- Heo, S., Y.X. Ynag, Z. Jin, M.S. Park, B.K. Yang, and B.J. Chae. 2008. Effects of dietary energy and lysine intake during late gestation and lactation on blood metabolites, hormones, milk composition and reproductive performance in primiparous sows. Can. J. Anim. Sci. 88: 247-255.
- Holyoake, P.K., G.D. Dial, T. Trigg, and V.L. King. 1995. Reducing pig mortality through supervision during the perinatal period. J. Anim. Sci. 73: 3543-3551.
- Hugher, P.E., and M.A. Varley. 1980. Lactation. In: Hughes, P.E. and M.A. Varley (eds.). Reproduction in the pig. Butterworth & Co, London, UK, p.136-158.
- Hurley, W.L. 2015. Composition of sow colostrum and milk. In: the gestation and lactating sow. Wageningen Academic Publishers 2015, 193-218.
- Inoue, T., 1981. Possible factors influencing immunoglobulin A concentration in swine colostrum. Am. J. Vet. Res. 42: 533-536.
- Inoue, T., K. Kitano, and K. Inoue. 1980. Possible factors influencing the immunoglobulin G concentration in swine colostrum. Am. J. Vet. Res. 41: 1134-1136.
- Isley, S.E., H.M. Miller, and C. Kamel. 2003. The effects of dietary supplementation with plant extracts on milk composition, feed intake and backfatt los in lactating sows. In: Manipulating Pig Prod. J.E. Patterson (Ed). Australasian Pig Sci. Assoc.
- Jackson, J.R., W.L. Hurley, R.A. Easter, A.H. Jensen, and J. Odle. 1995. Effects of induced or delayed parturition and supplemental dietary fat on colostrum and milk composition. J. Anim. Sci. 73:1906-1913.
- Jaeger, L.A., C.H. Lamar, G.D. Bottoms, and T.R. Cline. 1987. Growth-stimulating substances inprocine milk. Am. J. Vet. Res. 48: 1531-1533.

- Jensen, P.T. 1978. Trypsin inhibitor in sow colostrum and iits function. Ann. Rech. Vet. 9: 225-228.
- Jensen, A.R.., J. Elnif, D.G. Burrin, and P.T. Sangild. 2001. Development of intestinal immunoglobulin absorption and enzyme activities in neonatal pigs is diet dependent. J. Nutri. 131: 3259-3265.
- Ji, F., W.L. Hurley, and S.W. Kim. 2006. Characterization of mammary gland development in pregnant gilts. J. Anim. Sci. 84: 579-587.
- Johansen, M., Alban L., Kjærsgård, and M. Bækbo. 2004. Factors associated with suckling piglet average daily gain. Preventive Veterinary Medicine 63:91-102.
- Kapell, D.N.R.G., C.J. Ashworth, and P.W. Knap. 2011. Genetic parameters for piglet survival, litter size and birth weight or its variation within litter in sire and dam mines using Bayesian analysis. Livest. Sci. 135: 215-244.
- Kemp, B., N.M. Soede, P.C. Vesseur, F.A. Helmond, J.H. Spoorenberg, and K. Frankena. 1996. Glucose tolerance of pregnant sows is related to postnatal pig mortality. J. Anim. Sci. 74: 879-885.
- Keenan, T.W. 2001. Milk lipid globules and their surrounding membrane: a brief history and perspectives of future research. J. Mammary Gland Biol. Neoplasia, 6: 365-371.
- Kielland, C., V. Rootwelt, O. Reksen, and T. Framstad. 2015. The association between immunoglobulin G in sow colostrum and piglet plasma. J. Anim. Sci. 93: 4453-4462.
- Kilbride, A.L., M. Mendl, P. Statham, S. Held, M. Harris, S. Cooper, and L.E. Green. 2010. A cohort study of preweaning piglet mortality and farrowing accommodation on 112 commercial pig farms in England. Prev. Vet. Med. 104: 281-291.
- King, R.H., J.E. Pettigrew, J.P. McNamara, J.P. McMurtry, T.L. Henderson, and M.R. Hathaway. 1996. The effect of exogenous prolactin on lactation performance of first-litter sows given protein-deficient diets during the first pregnancy. Anim. Reprod. Sci. 41: 37-50.
- Klobasa, F., E. Werhahn, and J.E. Butler. 1981. Regulations of humoral immunity in the piglet by immunoglobulins of maternal origin. Res. Vet. Sci. 31: 195-206.
- Klobasa, F., and J.E. Butler. 1987. Absolutive and relative concentrations of immunoglobulins G, M, and A, and albumin in the lacteal secretion of sows of different lactation number. Am. J. Vet. Res. 48:176-182.

- Klobasa, F., C. Schröder, C. Stroot, and M. Henning. 2004. Passive immunisation in neonatal piglets in natural rearing- effect of birth order, birht weight, litter size and parity. Berliner und Munchener Tierarztliche Wochenschrift 117: 19-23.
- Klobasa, F., E. Werhahn E., and J.E. Butler. 1987. Composition of sow milk during lactation. J. Anim. Sci. 64:1458-1466.
- Klopfenstein, C., Y. Couture, G.P. Martineau, and E. Bouchard. 2002. Physiopathologie comparative de la lactation chez la truie et chez la vache. Médecin Véterinaire du Québec 32: 52-56.
- Knol, E.F., J.I. Leenhouwers, and T. van der Lende. 2002. Genetic aspects of piglet surival. Livest. Prod. Sci. 78: 47-55.
- Krakowski, L., J. Krzyzanowski, Z. Wron, K. Kostro, and A.K. Siwick. 2002. The influence of nonspecific immunostimulation of pregnant sows on the immunological value of colostrum. Vet. Imm. Immunopath. 87: 89-95.
- Krogh, U., C. Flummer, S.K. Jensen, and P.K. Theil. 2012. Colostrum and milk production of sows is affected by dietary conjugated linoleic acid. J. Anim. Sci. 90: 366-368.
- Lauridsen, C., and S.K. Jensen. 2005. Influence of supplementation of all-rac-α-tocopheryl acetate preweaning and vitamin C postweaning on α-tocopherol and immune responses of piglets. J. Anim. Sci. 83:1274-1286.
- Lecce, J.G. 1966. Glucose milliequivalents eaten by the neonatal pig and cessation of intestinal absorption of large molecules. J. Nutr. 90: 240-244.
- Le Dividich, J., P. Herpin, E. Paul, and F. Strullu. 1997. Effect of fat content of colostrum on voluntary colostrum intake and fat utilization in newborn pigs. J. Anim. Sci. 75:707-713.
- Le Dividich, J., P. Herpin, and R.M. Rosario-Ludovino. 1994. Utilization of colostral energy by the newborn pig. J. Anim. Sci. 72, 2082-2089.
- Le Dividich J., J.A. Rooke, and P. Herpin. 2005. Nutritional and immunological importance of colostrum for the new-born pig. J. Agric. Sci. 143:469-485.
- Leonard, S.G., T. Sweeney, B. Bahar, and J.V. O'Doherty. 2012. Effectt of maternal seaweed extract supplementation on suckling piglet growth, humoral immunity, selected microflora, and immune response after an ex vivo lipopolysaccharide challenge. J. Anim. Sci. 90:505-514.

- Leong, W.S., N. Navaratnam, M.J. Stankiewicz, A.V. Wallace, S. Ward, and N.J. Kuhn. 1990. Subcellular compartimentation in the synthesis of the milk sugars lactose and α-2,3-sialyllactose. Protoplasma 159: 144-159.
- Li, Y.Z., J.E. Anderson, and L.J. Johnson. 2012. Animal-related factors associated with piglet mortality in a bedded, group-farrowing system. Can. J. Anim. Sci. 92: 11-20.
- Li, J., H. Xia, W. Yao, T. Wang, J. Li, X. Piao, P. Thacker, G. Wu, and F. Wang. 2015. Effect of arginine supplementation during early gestation (day 1 to 30) on litter size and plasma metabolites in gilts and sows. J. Anim. Sci. 93: 5291-5303.
- Loisel, F., C. Farmer, P. Ramaekers, and H. Quesnel. 2013. Effect of high fibre intake durig late pregnancy on sow physiology, colostrum production and piglet performance. J. Anim. Sci. 91: 5269-5279.
- Loisel, F., C. Farmer, P. Ramaekers, and H. Quesnel. 2014. Colostrum yield and piglet growth during lactation are related to gilt metabolic and hepatic status prepartum. J. Anim. Sci. 92:2931-2941.
- Loisel, F., C. Farmer, H. van Hees, and H. Quesnel. 2015. Relative prolactin-to-progesterone concentrations around farrowing influence colostrum yield in primiparous sows. Dom. Anim. End. 53: 35-41.
- Mahan, D.C., Y.Y. Kim, and R.L. Stuart. 2000. Effect of vitamin E sources and levels on sow reproductive performance, serum, tissue, and milk α-tocoopherol contents over a five-parity period, and the effects on the progeny. J. Anim. Sci. 78: 110-119.
- Mahan, D.C. 1998. Relationship of gestation protein and feed intake level over a five-parity period using a high-producing sow genotype. J. Anim. Sci. 76: 533-541.
- Mahan, D.C., and J.L. Vallet. 1997. Vitamin and mineral transfer during fetal development and the early postnatal period in pigs. J. Anim. Sci. 75: 2731-2738.
- Michiels, J., M. De Vos, J. Missotten, A. Ovyn, S. De Smet, and C. Van Ginneken. 2013. Maturation of digestive function is retarded and plasma antioxidant capacity lowered in fully weaned low birth weight piglets. Brit. J. Nutr. 109: 65-75.
- Miller, M.B., T.G. Harsock, B. Erez, L. Douglass, and B. Alston-Mills. 1994. Effect of dietary calcium concentrations during gestation and lactation in the sow on milk compostion and litter growth. J. Anim. Sci. 72: 1315-1319.
- Miller, D.J., A.A. Wiley, J.C. Chen, C.A. Bagnell, and F.F. Bartol. 2013. Nursing for 48 hours from birth supports porcine uterine gland development and endometrial cell-compartment specific gene expression. Biol. Reprod. 88:4.

- Milligan, B.N., D. Fraser, and D.L. Kramer. 2001. Birth weight variation in the domestic pig: effects on offspring survival, weight gain and suckling behavior. Appl. Anim. Behav. Sci. 73:179-191.
- Milligan, B.N., D. Fraser, and D.L. Kramer. 2002. Within-litter birth weight variation in the domestic pig and its relation to preweaning survival, weight gain, and variation in weaning weights. Livest. Prod. Sci. 76: 181-191.
- Milon, A., A. Aumaitr, J. Le Dividich, J. Franz, and J.J. Metzger. 1983. Influence of birth prematurity on colostrum composition and subsequent immunity of piglets. Ann. Rech. Vet. 14: 533-540.
- Mitre, R., M. Etienne, S. Martinais, H. Salmon, P. Allaume, P. Legrand, and A.B. Legrand. 2005. Humoral defence improvement and haematopoesis stimulation in sows and offspring by oral supply of shark liver oil to mothers during gestation and lactation. Br. J. Nutr. 94: 753-762.
- Muns, R., X. Manteca, and J. Gasa. 2015. Effect of different management techniques to enhance colostrum intake on piglets' growth and mortality. Anim. Welf. 24: 185-192
- Monaco, M.H., Gronlund, D.E., Bleck, G.T., Hurley W.L., Wheeler, M.B., and S.M. Donovan. 2005. Mammary specific transgenic over-expression of insulin-like growth factor-I increases pig milk IGF-I and IGF binding proteins, with no effect on milk composition or yield. Transgenic Research 14: 761-773.
- Mostyn, A., S. Sebert, J.C. Litten, K.S. Perkins, J. Laws, M.E. Symonds, and L. Clarke. 2006. Influence of porcine genotype on the abundance of thyroid hormones and leptin in sow milk and its impact on growth, metabolism and expression of key adipose tissue genes inoffspring. J. End. 190: 631-639.
- Nakamura, T., T. Nemoto, and T. Saito. 1995. Artificial increase in the suckling frequence of piglets due recorded grunting and suckling sounds. J. Anim. Sci. 73: 84-86.
- Nemec, M., G. Butler, M. Hidiroglou, E.R. Farnworth, and K. Nielsen. 1994. Effect of supplementing gilts' diets withdifferent levels of vitamin E and different fats on the humoral and cellular immunity of gilts and their progeny. J. Anim. Sci. 72: 665-676.
- Nechvatalova, K., H. Kudlackova, L. Leva, K. Babickova, and M. Faldyna. 2011. Transfer of humoral and cell-mediated immunity via colostrum in pigs. Vet. Imm. Immunopath. 142: 95-100.

- Newman, K.E., and M.C. Newman. 2001. Evaluation of mannan oligosaccharide on the microflora and immunoglobulin status of sows and piglet performance. J. Anim. Sci 79: 189.
- Nguyen, T.V., L. Yuan, S.P. Azevedo, K.I. Jeong, A.M. Gonzales, and L.J. Saiif. 2007. Transfer of maternal cytokines to suckling pigelts: in vivo and in vitro models with implications for immunomodulation of neonatal immunity. Vet. Imm. Immunopath. 117: 236-248.
- Noblet, J., and M. Etienne. 1987.Body composition, metabolic rate and utilization of milk nutrients in suckling piglets. Reprod. Nutr. Dev.27: 829–839.
- Oliviero C., M. Heinonen, A. Valros, and O.A.T. Peltoniemi. 2010. Environmental and sow-related factors affecting the duration of farrowing. Anim. Reprod. Sci. 119: 85-91.
- Ollivier-Bousquet, M., and E. Devinoy. 2005. Physiology of lactation: old questions, new approaches. Livest. Prod. Sci. 163-173.
- O'Quinn, P.R., D.W. Funderburke, and G.W. Tibbetts. 2001. Effects of dietary supplementation with mannan oligosaccharids on sow and litter performance in a commercial production system. J. Anim. Sci 79: 212.
- Panzardi, A., M.L. Bernardi, A.P. Mellagi, T. Bierhals, F.P. Bortolozzo, and I. Wentz. 2013. Newborn piglet traits associated with survival and growth performance until weaning. Preventive Veterinary Medicine 110: 206-213.
- Paredes, S.P., A.J.M. jansman, M.W.A. Verstegen, A. Awati, W. Buist, L.A. den Harotg, H.M.J. van Hees, N. Quiniou, W.H. Hendriks, and W.J.J. Gerrits. 2012. Analysis of factors to predict piglet body weight at the end of the nursery phase. J. Anim. Sci. 90:3243-3251.
- Pattinson, S.E., and E.W. Thomas. 2004. The effect of sire breed on colostrum production of crossbred ewes. Livest. Prod. Sci. 86: 47-53.
- Payne, L.C., and C.L. Marsh. 1962. Absorption of gamma globulin by the small intestine. Fed. Proc. 21:909-912.
- Pedersen, L.J., J. Malmkvist, T. Kammersgaard, and E. Jørgensen. 2013. Avoiding hypothermia in neonatal pigs: effect of duration of floor heating at different room temperatures. J. Anim. Sci. 91: 425-432.
- Père M.C., and M. Etienne. 2007. Insulin sensitivity during pregnancy, lactation, and postweaning in primiparous gilts. J. Anim. Sci. 85: 101-110.

- Père M.C., M. Etienne, and J.Y. Dourmad. 2000. Adaptations of glucose metabolism in multiparous sows: effects of pregnancy and feeding level. J. Anim. Sci. 78: 2933-2941.
- Peters, J.C., D.C. Mahan, T.G. Wiseman, and N.D. Fastinger. 2010. Effect of dietary organic and inorganic micromineral source and level on sow body, liver, colostrum, mature milk, and progeny mineral compositions over six parities. J. Anim. Sci. 88: 626-637.
- Pettigrew, J.E., A.F. Sower, S.G. Cornelius, and R.L. Moser. A comparison of istope dilution and weigh-suckle-weigh methods for estimating milk intake by pigs. Can. J. Anim. Sci. 65: 989-992.
- Pierzynowski, S., G. Ushakov, T. Kovalenko, I. Osadchenko, K. Goncharov, P. Gustavsson, O. Prykhodko, J. Wolinski, M., Slupecka, P. Ochniewics, B. Weström, and G. Skibod. 2014. Impact of colostrum and plasma immunoglobulin intake on hippocampus structure during early postnatal development in pigs. Int. J. Dev. Neurosci. 35: 64-71.
- Pinelli-Saavedra, A., J.R. Scaife, A.M. Calderon de la Barca, J.R. Valenzuela, and H. Celaya. 2008. Effect of supplementation with vitamin E and vitamin C on immune response of sows and their litters in hot environments. Proc. Nutr. Soc. 60: 25a.
- Plaut, K.I., R.S. Kensinger, L.C. Griel, and J.F. Kavanaugh. 1989. Relationships among prolactin binding, prolactin concentrations in plasma and metabolic activity of the porcine mammary gland. J. Anim. Sci. 67: 1509-1519.
- Prawirodidgdo, S., R.H. King, A.C. Dunkin, and H. Dove. 1990. Evaluation of techniques for estimating milk production by sows: 1-deuterium oxide dilution method for estimating milk intake by piglets. Asian Austr. J. Anim. Sci. 3: 135-141.
- Quesnel, H. 2011. Colostrum production by sows: variability of colostrum yield and immunoglobulin G concentrations. Animal 5: 1546-1553.
- Quesnel, H., L. Brossard, A. Valancogne, and N. Quiniou. 2008. Influence of some sow characteristics on within-litter variation of piglet birth weight. Animal 2 (12): 1842-1849.
- Quesnel, H., C. Farmer, and N. Devillers. 2012. Colostrum intake: influence on piglet performance and factors of variation. Livest Sci 146: 105-114.
- Quesnel, H., N. Quiniou, H. Roy, A. Lottin, S. Boulot, and F. Gondret. 2014. Supplying dextrose before insemination and L-arginine during the last third of

pregnancy in sow diets: effects on within-litter variation of piglet birth weight. J. Anim. Sci. 92: 1445-1450.

- Quiniou, N., J. Dagorn, and D. Gaudré. 2002. Variation of piglets' birth weight and consequences on subsequent performance. Livest. Prod. Sci. 78:63-70.
- Rahman, K.M., J.E. Lovich, C. Lam, M.E. Camp, A.A. Wiley, F.F. Bartol, and C.A. Bagnell. 2014. Nursing supports neonatal porcine testicular development. Dom. Anim. End. 48: 84-92.
- Rehfeldt, C., A. Tuchscherer, M. Hartung, and G. Kuhn. 2008. A second look at the influence of birth weight on carcass and meat quality in pigs. Meat Science 78: 170-175.
- Rooke, J.A., and I.M. Bland. 2002. The acquisition of passive immunity in the newborn piglet. Livest. Prod. Sci. 78:13-23.
- Rooke, J.A., M. Shanks, and S.A. Edwards. 2000. Effect of offering maize, linseed or tuna oils throughout pregnancy and lactation on sow and piglet tissue composition and piglet performance. Anim. Sci. 71: 289-299.
- Rooke, J.A., P. Penny, P.C. Penn, G.W. Horgan, A.M. Finch, S.A. Edards, A.G. Sinclair, S. Pkiyach, and R. Cordoba. 2001. The effect of feeding salmon oil to sows throughout pregnancy on preweaning mortality of piglets. Anim. Sci. 73: 489-500.
- Rutherford, K.M.D., E.M. Baxter, R.B. D'Eath, S.P. Turner, G. Arnotte, R. Roehe, B. Ask, P. Sandøe, V.A. Moustsen, F. Thorup, S.A. Edwards, P. Berg, and A.B. Lawrence. 2013. The welfare implications of large litter size in the domestic pig I: biological factors. Anim. Welfare 22: 199-218.
- Salmon, H., M. Berri, V. Gerdts, and F. Meurens. 2009. Humoral and cellular factors of maternal immunity in swine. Dev. Comp. Imm. 33: 284-393. Schanbacher, F.L., R.S. Talhouk, and F.A. Murray. 1997. Biology and origin of bioactive peptides in milk. Livest. Prod. Sci. 50:105-123.
- Shankar, B.P., H.S. Madhusudhan, and D.B. Harish. 2009. Preweaning mortality in pig – causes and management. Vet. World 2: 236-239.
- Shennan, D.B., and M. Peaker. 2000. Transport of milk constituents by the mammary gland. Phys. Reviews. 80 (3): 925-951.
- Simmen, F.A., K.Y. Whang, R.C.M. Peterson, G.A. Bisshop, and K.M. Irvin. 1990. Lactational variation and relationship to postnatal growth of insulin-like growth factor I in mammary secretions from genetically diverse sows. Dom. Anim. End. 7: 199-206.

- Slupecka, M., J. Wolinski, and S.G. Pierzynowski. 2010. Crypt fission contributes to postnatal epithelial growth of the small intestine in pigs. Livest. Sci. 133: 34-37.
- Sorensen, M.T., K. Sejresen, and S. Purup. 2002. Mammary gland development in gilts. Livest. Prod. Sci. 75: 143-148.
- Spence, C.A., R. Boyd, D.E. Bauman, W.R. Butler, and C.D. Wray. 1984. Effects of exogenous growth hormone on fetal energy storage and lactation performance in sows. J. Anim. Sci. 59: 246.
- Tanghe, S., and S. De Smet. 2013. Does sow reproduction and piglet performance benefit from the addition. The Vet. J. 197: 560-569.
- Taugbol, O., T. Framstad, and K. Saarem. 1993. Supplements of cod liver oil to lactating sows. Influence on milk fatty acid composition and growth performance of piglets. J. Vet. Med. 40: 437-443.
- Taverne, M., M.M. Bevvers, J.M.C. Bradshaw, S.J. Dieleman, A.H. Willemse, and D.G. Porter. 1982. Plasma concentrations of prolactin, progesterone, relaxin and oestradiol-17b in sows treated with progesterone, bromocriptine or indomethacin during late pregnancy. J. Reprod. Fertil. 65:85-96.
- Theil, P.K. 2015. Transition feeding of sows. In: C. Farmer, editor, The gestating and lactating sow. Wageningen Academic Publishers, Wageningen, The Netherlands. P 147-172.
- Theil, P.K., T.T. Nielssen, N.B. Kristensen, R. Abouriau, V. Nielsen, and C. Lauridsen. 2002. Estimation of milk production in lactating sows by determination of deuterated water turnover in three piglets per litter. Acta Agr. Scand. Anim. Sci. 52: 221-232.
- Theil, P.K., G. Cordero, P. Henckel, L. Puggaard, N. Oksbjerg, and M.T. Sørensen. 2011. Effects of gestation and transition diets, piglet birth weight, and fasting time on depletion of glycogen pools in liver and 3 muscles of newborn piglets. J. Anim. Sci. 89: 1805-1816.
- Theil, P.K., C. Flummer, W.L. Hurley, N.B. Kristensen, R.L. Labouriau, and M.T. Sorensen. 2014a. Mechanistic model to predict colostrum intake based on deuterium oxide dilution technique data and impact of gestation and prefarrowing diets on piglet intake and sow yield of colostrum. J. Anim. Sci 92: 5507-5519.
- Theil, P.K., C. Lauridsen, and H. Quesnel. 2014b. Neonatal piglet survival: Impact of sow nutrition around parturition on fetal glycogen deposition and production and composition of colostrum and transient milk. Animal 8: 1021-1030.

- Theil, P.K., K. Sejrsen, W.L. Huryley, R. Labouriau, B. Thomson, and M.T. Sørensen. 2006. Role of suckling in regulating cell turnover and onset and maintenance of lactation in individual mammary glands of sows. J. Anim. Sci. 84: 1691-1698.
- Theil, P.K. 2015. Transition feeding of sows. In: C. Farmer, editor, The gestating and lactating sow. Wageningen Academic Publishers, Wageningen, The Netherlands. P 147-172.
- Tuboly, S., S. Bernath, R. Glavits, and L. Medveczky. 1988. Intestinal absorption of colostral lymphoid cells in newborn piglets. Vet. Imm. Immunopath. 20: 75-85.
- Tuboly, S., and S. Bernath. 2002. Intestinal absorption of colostral lymphoid cells in newborn animals. Adv. Exp. Med. Biol. 503: 107-114.
- Tucker, H.A. 1981. Physiological control of mammary growth, lactogenesis and lactation. J. Dairy Sci. 64: 1403-1421.
- Turner, C.W. 1952. The anatomy of the mammary gland of swine. In: Turner, C.W. (ed.). The mammary gland. I. The anatomy of the udder of cattle and domestic animals. Lucas Brothers, Columbia, MO, USA, p. 279-314.
- Tuchscherer, M., B. Puppe, A. Tuchscherer, and U. Tiemann. 2000. Early identification of neonates at risk: traits of newborn piglets with respect to survival. Theriogenology 54: 371-388.
- Vadmand, C.N., U. Krogh, C.F. Hansen, and P.K. Theil. 2015. Impact of sow and litter characteristics on colostrum yield, time for onset of lactation, and milk yield of sows. J. Anim. Sci. 93: 2488-2500.
- Vallet, J.L., J.R. Miles, and L.A. Rempel. 2013. A simple novel measure of passive transfer of maternal immunoglobulin is predictive of preweaning mortality in piglets. The Vet. J. 195: 91-97.
- Vallet, J.L., J.R. Miles, L.A. Rempel, D.J. Nonneman, and C.A. Lents. 2015. Relationships between day one piglet serum immunoglobuline immunocrit and subsequent growth, puberty attainment, litter size, and lactation performance. J. Anim. Sci. 93: 2722-2729.
- Van den Brand, H., N.M. Soede, B. Kemp. 2006. Supplementation of dextrose to the diet during the weaning to estrus interval affects subsequent variation in within-litter pigelt birth weight. Anim. Reprod. Sci. 91: 353-358.
- Vanderhaeghe, C., J. Dewulf, A. de Kruif, and D. Maes. 2013. Non-infectious factors associated with stillbirth in pigs: a review. Anim. Reprod. Sci. 139: 76-88.

- Varley, M.A., A. Maitland, and A. Towle. 1986. Artificial rearing of piglets: the administration of two sources of immunoglobulins after birth. Anim. Prod. 43:121-126.
- Vasdal, G., and I.L. Larsen. 2012. A note on teat accessibility and sow parity – consequences for newborn piglets. Livest. Sci. 146: 91-94.
- Vasdal, G., I. Østensen, M. Melišová, and, B. Bozděchová. 2011. Management routines at the time of farrowing-effects on teat success and postnatal piglet mortality from loose housed sows. Livestock Science 136: 225-231.
- Wagstrom, E.A., K.J. Yoon, and J.J. Zimmerman. 2000. Immune components in porcine mammary secretions. Viral immunology 13: 383-397.
- Werhahn, E., F. Klobasa, and J.E. Butler. 1981. Investigation of some factors which influence the absorption of IgG b the neonatal piglet. Vet. Immunol. Immunopathol. 2:35-51.
- Weström, B.R., R. Ekman, L; Svensden, J. Svendsen, and B.W. Karlsson. 1987. Levels of immunoreactive insulin, neurotensin, and bombesin in porcine colostrum and milk. J. Pedriat. Gastroenterol. Nutri. 6: 460-465.
- Whitacre, M.D., and W.R. Trelfall. 1981. Effects of ergocryptine on plasma prolactin, luteinizing hormone, and progesterone in the periparturient sow. Am. J. Vet. Res. 42: 1538-1541.
- White, K.R., D.M. Anderson, and L.A. Bate. 1996. Increasing piglet survival through an improved farrowing management protocol. Can. J. Anim. Sci. 76: 491-495.
- Whitely, J.L, P.E. Hartmann, D.L. Willcox, G.D. Bryant-Greenwood, and F.C. Greenwood. 1990. Initiation of parturition and lactation in the sow: effects of delaying parturition with medroxyprogesterone acetate. J. Endocrinol. 124: 475-484.
- Wientjes, J.G.M., N.M. Soede, E.F. Knol, H. van den Brand, and B. Kemp. 2013. Piglet birth weight and litter uniformity: effects of weaning-to-pregnancy interval and body condition changes in sows of different parities and crossbred lines. J. Anim. Sci. 91: 2099-2107.
- Williams, P.P. 1993. Immunomodulating effects of intestinal absorbed maternal colostral leukocytes by neonatal pigs. Can. J. Vet. Res. 57: 1-8.
- Willcox, D.L., P.G. Arthur, P.E. Hartmann, and J.L. Whitely. 1983. Perinatal changes in plasma oestradiol-17b, cortisol and progesterone and the initiation of lactation in sows. Aust. J. Biool. Sci. (36): 173-181.

- Wolf, J., E. Zakova, and E. Groeneveld. 2008. Within-litter variation of birth weight in hyperprolific Czech Large White sows and its relation to litter size traits, stillborn piglets and losses until weaning. Livest. Sci. 115: 195-205.
- Wuryastuti, H., H.D. Stowe, R.W. Bull, and E.R. Miller. 1993. Effects of vitamin E and selenium on immune responses of peripheral blood, colostrum, and milk leukocytes f sows. J. Anim. Sci. 71: 2464-2472.
- Xu, R.J. 2003. Composition of porcine milk. In: The neonatal pig. Gastrointestinal physiology and nutrition. R. J. Xu, and P. Cranwell (Eds.). Nottingham University Press, United Kingdom, p. 213-246.
- Xu, R.J., F. Wang, and S.H. Zhang. 2000. Postnatal adaptation of the gastrointestinal tract in neonatal pigs: a possible role of milk-borne growth factors. Livest. Prod. Sci. 66: 95-107.
- Yan, W. , A.A. Wily, A.D. Bathgat, A.L. Frankshun, S. Lasano, B.D. Crean, B.G. Steinetz, C.A. Bagnell, and F.F. Bartol. 2006. Expression of LGR7 and LGR8 by neonatal procine uterine tissues end transmission of milk-born relaxin into the neonatal circulation by suckling. End. 147: 4303-4310.
- Zaleski, H.M., R.J. Winn, R.L. Jennings, and O.D. Sherwood. 1996. Effects of relaxin on lactational performance in ovariectomized gilts. Biol. Reprod. 55: 671-675.
- Zheng H.C., J.X. Liu, J.H. Yao, Q. Yuan, H.W. Ye, J.A. ye, and Y.M. Wu. 2005. Effect of dietary sources of vegetable oils on performance of high-yielding lactating cows and conjugated linoleic acids in milk. J. Dairy Sci. 88: 2037-2042.
- Zhou, Q., R.G. He, X. Li, and S.R. Liao. 2003. Protease inhibitors in porcine colostrum: potency assessment and initial characterization. Asian Austr. J. Anim. Sci. 16: 1822-1829.
- Zou S., D.G. McLaren, and W.L. Hurley 1992. Pig colostrum and milk composition: comparisons between Chinese Meishan and US breeds. Livest. Prod. Sci. 30:115-127.

Chapter 2

Aims

II. AIMS

It is well established that colostrum intake influences preweaning mortality and performance. Some authors presumed long-term effects, however, studies investigating such long-term effects are lacking. So far, most trials on colostrum in pigs were conducted under experimental conditions or in one commercial herd and hence, studies about colostrum's short- and long-term effects in commercial pig herds would be of great interest because of their practical relevance and external validity. In order to optimize colostrum management, factors determing the huge variation of colostrum yield, composition and intake should be unravelled. Especially, insights regarding genetics, gestation length and birth assistance are warranted. Therefore, studies including different breeds and without performing parturition induction are of great value. Finally, several management strategies are supposed to improve colostrum intake, but scientific studies investigating the impact of these management strategies on colostrum intake are scarce. Especially studies evaluating measures one-by-one and estimating colostrum intake in addition to mortality and performance are recommended.

Therefore, the specific objectives were to investigate:

- The short-term as well as the long-term effects of colostrum intake on pig performance and mortality in commercial pig production.
- Sow, litter and parturition factors affecting sows' colostrum yield and colostrum composition.
- Sow and piglet factors determining the variation of piglets' colostrum intake between and within litters.
- The effect of a commercial energy supplement to neonatal (very) low birth weight piglets on mortality, daily weight gain, weaning weight as well as on colostrum intake.

Chapter 3

Long-term effects of colostrum intake in piglet performance and mortality

I. Declerck, J. Dewulf, S. Sarrazin, and D. Maes

Journal of Animal Science (2016) 94: 1633-1643.

III. LONG-TERM EFFECTS OF COLOSTRUM INTAKE IN PIGLET MORTALITY AND PERFORMANCE

ABSTRACT

The present study investigated the long-term effects of colostrum intake on performance and mortality in pigs. A total of 1,455 live-born piglets on ten commercial herds were followed-up from birth until 22 weeks of age. Pigs were individually weighed at birth, at weaning, at onset (intermediate weight) and during the fattening period (finishing weight). Colostrum intake was calculated by the mechanistic model developed by Theil et al. (2014a). One linear mixed model was fitted to model the possible associations between colostrum intake and weight at weaning, intermediate and finishing period. In addition to colostrum intake as main predictor of interest, also other predictor variables were tested namely birth weight, birth order, sex, breed and the interval between birth and first suckling ($\mathbf{t_{FS}}$). Colostrum intake and birth weight were positively associated with weaning ($P < 0.001$), intermediate ($P < 0.001$) and finishing ($P < 0.001$) weight. Furthermore, higher colostrum intake is more beneficial to weaning ($P < 0.001$), intermediate ($P < 0.001$) and finishing ($P = 0.02$) weight in piglets with lower birth weights. Birth order was positively associated with weight at each measurement time ($P = 0.01$). Sex only affected finishing weight ($P < 0.001$). Some breeds differed in piglets' weight at onset or during the fattening period. The association between t_{FS} and weaning weight differed by breed. Three generalized linear mixed models were performed to model the probability of dying either during the suckling, the nursery or the fattening period. Colostrum intake, birth weight, birth order, sex, breed and t_{FS} were tested. Preweaning mortality was negatively associated with colostrum intake ($P < 0.001$) and birth weight ($P = 0.004$) and positively with t_{FS} ($P < 0.001$). Mortality during the nursery period was negatively associated with colostrum intake ($P < 0.001$) and birth weight ($P = 0.002$). The negative association between colostrum intake and mortality during the suckling ($P < 0.001$) and nursery ($P = 0.008$) period was more pronounced in piglets with lower birth weights. Mortality during fattening was associated with weaning ($P = 0.04$) and intermediate ($P = 0.006$) weight. In conclusion, colostrum intake significantly influences piglets' short-term and long-term performance and mortality. As colostrum yield is reported to be independent of litter size, sufficient colostrum intake per piglet is crucial especially in hyper-prolific sows.

Key words: colostrum, long-term, mortality, performance, piglet

INTRODUCTION

Colostrum intake by neonatal piglets is essential as colostrum is the sole external supply of energy for thermoregulation and body growth (Herpin et al., 2005; Le Dividich et al., 2005). Furthermore, colostrum provides newborn piglets with immunological protection (Rooke and Bland, 2002) and growth factors promoting intestinal growth and function (Wang and Xu, 1996; Xu et al., 2000; Thymann et al., 2006). In the context of reducing antibiotic use, sows are vaccinated to protect their offspring against diseases through maternal immunity, which strengthens the crucial importance of colostrum intake in nowadays high prolific pig production (Farmer and Quesnel, 2009; Quesnel et al., 2012). It is well known that insufficient colostrum intake is a major cause of preweaning mortality (Edwards, 2002; Le Dividich et al., 2005; Decaluwé et al., 2014). Devillers et al. (2011) observed a preweaning mortality rate of 43.4% in piglets with a colostrum intake lower than 200 g, whereas this rate was 7.1% in piglets with a higher colostrum intake. Some authors have presumed long-term effects of colostrum intake on mortality and performance (Le Dividich et al., 2005; Devillers et al., 2011; Quesnel et al., 2012, Decaluwé et al., 2014). However, studies investigating such long-term effects of colostrum intake are still scarce. Furthermore, most trials on colostrum in pigs are conducted under experimental conditions or in one commercial herd (Devillers et al., 2005; 2011; Decaluwé et al., 2013; 2014; Ferrari et al., 2014). Therefore, this study aimed to investigate the short-term as well as the long-term influence of colostrum intake on performance and mortality on ten commercial pig herds.

MATERIALS AND METHODS

Study population, animal handling and data collection

The study was approved by the Ethical Committee of the Faculty of Veterinary Medicine, Ghent University (EC2011/085) and was performed on ten different commercial pig herds in Flanders (northern Belgium). Five different sow breeding lines were represented in these farrow-to-finish herds: four commercial crossbred sows (PIC, Topigs, Hypor and Danbred) and one own crossbred landrace. On each herd a single sow breeding line was presented and semen from Piétrain boars was purchased from a commercial AI-centre. Main herd characteristics are given by **Table 1**. Within a herd, ten sows were selected based on the expected day of farrowing. All parturitions were supervised 24 h a day. When a piglet was born, the back was dried with a paper towel, an individual ear tag was placed in the right ear the birth weight was measured and the birth order was marked on the back. Subsequently, piglets were placed back on the place where they were taken (mostly at the sows' vulva). Furthermore, time of birth and time of first suckling was registered for each piglet. Piglets were individually weighed 24 h after birth of the first littermate. Cross fostering of piglets was not allowed before the second day of life. On all herds, male piglets were surgically castrated during the first week of life. Piglets were individually weighed at weaning (21 ± 0.9 d of age), at entering the fattening unit (76 ± 7.2 d of age) and during the fattening period (154 ± 2.7 d of age).

Table 1. *Herd characteristics and averages regarding colostrum intake, weight and mortality during 1,374* piglets' lifetime on ten commercial Belgian pig herds*

	Herd number									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Breed of sows	Own crossbred landrace	PIC	Topigs	Topigs	Topigs	Hypor	PIC	Danbred	Danbred	Hypor
Number of sows per herd	300	1700	450	520	450	600	700	750	300	600
Batch-production-system, weeks	3	2	5	5	4	4	3	2	4	4
Lactation period, weeks	4	3	3	3	3	3	4	3	3	3
Piglets weaned/sow/year	25	27	30	25	26	27	26	28	30	27
Colostrum intake, g	378	394	386	350	345	423	387	289	325	430
Weight, kg										
Birth	1.39	1.19	1.30	1.19	1.24	1.41	1.33	1.20	1.27	1.39
Weaning	6.63	5.59	6.52	5.52	6.61	5.98	6.27	4.83	5.99	6.13
Intermediate	21.27	24.70	25.61	27.35	24.07	26.45	24.86	21.38	23.99	26.99
Fattening	77.42	86.95	81.55	83.38	75.38	84.88	85.81	73.75	80.12	81.11
Mortality, %										
First day of life	3.3	5.1	6.9	4.5	6.7	9.0	7.0	3.1	6.0	6.0
Pre- weaning	7.4	6.2	15.2	9.0	20.1	5.7	10.4	11.8	15.5	16.3
Nursery	1.8	3.8	6.5	6.6	3.7	0.9	13.6	18.3	2.1	9.7
Fattening unit	0.9	0.01	1.7	1.8	3.9	1.7	0	0.01	0.03	0

** Colostrum intake from piglets that died during the first 24h was not calculated and hence, mortality during the first day of life was not included in the pre-weaning mortality data.*

Calculations

Colostrum intake was calculated by the mechanistic model as described by Theil et al. (2014a). This model allows an accurate quantification of colostrum intake by sow-reared piglets with normal suckling pattern and physical activity. The model is based on 24 h weight gain (WG, g), birth weight (BW_b, kg), and duration of colostrum intake (D, minutes). Duration of colostrum intake is the time between first and second weighing. The equation is the following: $-106 + 2.26\ WG + 200\ BW_b + 0.111\ D - 1414\ WG/D + 0.0182\ WG/BW_b$. Time between birth and first suckling ($\mathbf{t_{FS}}$) was calculated based on time of birth and time of first suckling. Because of the varying age at weaning, at entering and during the fattening unit, weights were adjusted to an average age of 21, 76 and 154 d, respectively (Douglas et al., 2013). These adjusted weights were used for analysis and are also referred as weaning, intermediate and finishing weight, respectively. Mortality was registered as mortality during the suckling period (referred as preweaning mortality), the nursery and the fattening period. Mortality during the first day of life was not included in the preweaning mortality data as colostrum intake from piglets that died during the first 24 h was not calculated.

Statistical analysis

Predictor variables

Besides colostrum intake as main predictor of interest, the following variables were considered to be included for the weight and mortality analysis: birth weight, birth order, sex, breed and t_{FS}. Basic descriptive statistics were used to explore predictor and outcome variables.

Weight analysis

Single linear mixed model was used to model the possible associations between weight (at weaning, intermediate and finishing period) and colostrum intake, birth weight, birth order, sex, breed and t_{FS}. The study was performed on 10 herds (k = 1, …, 10) and 10 sows (j = 1,…,10) per herd were included. The number of piglets i per sow varied from 7 to 24. The outcome variable weight was measured at weaning (t = 1), at entering the fattening unit (t = 2) and during the fattening unit (t = 3). The outcome Yijkt represents the weight of piglet i, from sow j, in herd k, at measurement t and was modeled as: Y_ijkt= βX_ijkt+u_k+v_j(k)

+ε_(i(jk)t). The fixed part of the model is represented by βXijkt while random intercepts were used with u_k and v_j(k) normally distributed random effects with mean 0 and variances σ^2 and τ^2, respectively. The parameters u_k are herd-specific intercepts, measuring the deviation of the weight of each herd from the average weight. In a similar way, the parameters v_j(k) are sow-specific parameters, measuring the deviation of the weight within each litter. The notation j(k) is used to indicate the clustering of sows j in herds k. The variability of piglets, nested within sows and herds, at time t is denoted by ε_(i(jk)t). An unstructured covariance matrix was assumed for this residual variance. By the use of herd- and sow-specific parameters, confounding factors at herd and sow level were taken into account. Analysis was performed using the Mixed procedure in SAS 9.4 (SAS Institute Inc., Cary, USA). Initially, univariable models between weight and each predictor variable were examined. The way continuous predictor variables (colostrum intake, birth weight, birth order and t_{FS}) could enter the model was examined by the Loess curves between each individual predictor variable and weight and by the scaled residuals of the univariable models. If necessary, transformation of the predictor variables or inclusion of higher order effects was considered. Regarding t_{FS}, a log transformation was performed to obtain a linear association with the outcome variable. Secondly, a fully saturated main effects model was fitted, i.e. all main effects, their interaction with time and three-way interactions between predictor variables and time. The model was simplified in a stepwise backward manner, keeping only the significant terms in the model. A variable was considered to act as a confounder if its removal made the regression coefficients of the remaining variables undergo a relative change > 25% (Noordhuizen et al., 2001). Statistical significance was assessed at $P < 0.05$ based on likelihood ratio tests. The scaled residuals were explored to assess model assumptions.

Mortality analysis

Three separate models were fitted to investigate the probability of dying during the suckling, the nursery and fattening period. To account for clustering of piglets within sows and sows within herds, generalized linear mixed models with a logit link function and random intercepts were fitted. Analyses were performed using the Glimmix procedure in SAS 9.4 (SAS Institute Inc., Cary, NC). First, univariable models for each predictor variable were fitted. Regarding tFS, a log transformation was performed to obtain a linear association with the logit of the outcome. Subsequently, all variables with $P < 0.25$ were combined in a

multivariable model by a stepwise backward model building procedure. Statistical significance in this step was assessed at $P<0.05$. Finally, all two-way interactions were tested and significant interactions ($P<0.05$) were withheld. To evaluate the goodness-of-fit of the final model, the raw residuals were calculated by subtracting the predicted outcome from the observed outcome. These raw residuals were further explored by univariate and bivariate analysis.

RESULTS

Descriptive results

Mortality and performance of 1,374 piglets alive after the first day were analysed. The average ± SEM (range) weaning, intermediate and finishing weight was 5.82 ± 0.18 kg (1.44 to 9.98); 24.00 ± 0.66 kg (8.15 to 39.45) and 79.54 ± 1.45 kg (28.01 to 109.00), respectively. The percentage of preweaning mortality, mortality in the nursery and the fattening unit was 11.9, 6.9 and 1.5%, respectively. Colostrum intake per piglet averaged 367 ± 3.8 g (0 to 899). Descriptive results of the other predictor variables are summarized in **Table 2**. At herd level, descriptive data regarding colostrum intake, weight and mortality are given by **Table 1**.

Table 2. *Descriptive statistics of potential predictor variables determining piglet mortality and performance on ten commercial herds*

Predictor variable	%	Mean ± SEM	Minimum	Maximum
Birth weight, kg		1.27 ± 0.03	0.30	2.40
Birth order			1	24
Sex				
Female	51			
Male	49			
Breed				
Own crossbred landrace	9			
PIC	18			
Topigs	30			
Hypor	19			
Danbred	24			
t_{FS}, minutes		52 ± 1.2	3	410

t_{FS} = the interval between birth and first suckling, minutes.

Weight analysis

The final results of the multivariable mixed linear regression analysis with weight (at weaning, entering and during fattening) as outcome variable are given by **Table 3**. To give a biological plausible interpretation to the intercept, the predictor variables birth weight, birth order and log(t_{FS}) were rearranged by subtracting the mean birth weight (1.27 kg), one rank and the mean log(t_{FS}) (3.6), respectively. Hence, the intercept represents a male Danbred piglet without colostrum intake, with a mean birth weight, born as first and a mean t_{FS}. The intercept is associated with a mean weaning, entering and finishing weight of 4.17 kg (95% CI 3.54; 4.80), 19.18 kg (95% CI 18.03; 20.33) and 73.02 kg (95% CI 70.48; 75.56), respectively. Both colostrum intake and birth weight were positively associated with weaning ($P < 0.001$), intermediate ($P < 0.001$) and finishing ($P < 0.001$) weight. Furthermore, both predictor variables were negatively interacting on weaning ($P < 0.001$), intermediate ($P < 0.001$) and finishing ($P = 0.02$) weight. Due to this negative interaction, higher colostrum intake was more beneficial in piglets with lower birth weights as illustrated by **Figure 1**, **2** and **3**. Regarding piglets weighing the mean birth weight, a colostrum intake increase of one g is associated with an increase of the weaning, entering and finishing weight of 3.5 g (95% CI 2.8; 4.2), 10 g (95% CI 8; 13) and 17 g (95% CI 10; 23), respectively. Regarding piglets without colostrum intake, weighing one kg more at birth was associated with an increase of the weaning, entering and finishing weight with 3.15 kg (95% CI 2.55; 3.74), 9.03 kg (95% CI 6.83; 11.23) and 16.98 kg (95% CI 11.47; 22.49), respectively. Birth order was positively associated with weight. An increase in birth order of one unit was associated with an increase in weight at each time point of 10 g (95% CI 0; 30). Sex influenced only finishing weight ($P < 0.001$). Female fattening pigs weighed on average 3.61 kg (95% CI 2.46; 4.77) less compared to male fatteners. Some breeds differed in weight and the association between t_{FS} and weight was also different among breeds. Compared with Danbred piglets and considering piglets with a mean t_{FS}, piglets of own crossbred landrace ($P = 0.002$) had a lower intermediate weight, whereas piglets of PIC ($P = 0.02$), Topigs ($P < 0.001$) and Hypor ($P < 0.001$) had a higher intermediate weight. Considering piglets with a mean t_{FS}, PIC ($P < 0.001$), Topigs ($P = 0.005$) and Hypor ($P = 0.007$) piglets weighed more at the age of 22 wk than Danbred piglets. As mentioned before, the association between t_{FS} and weaning weight differed by breed. For Danbred pigs, an increase of 2.7 minutes in t_{FS} resulted in a 200g weight increase (95% CI 29; 375). For PIC and Topigs pigs, an increase of 2.7 minutes in t_{FS}

resulted in a 193 g (95% CI -25; 411) and 320 g (95% CI 136; 503) weight decrease, respectively.

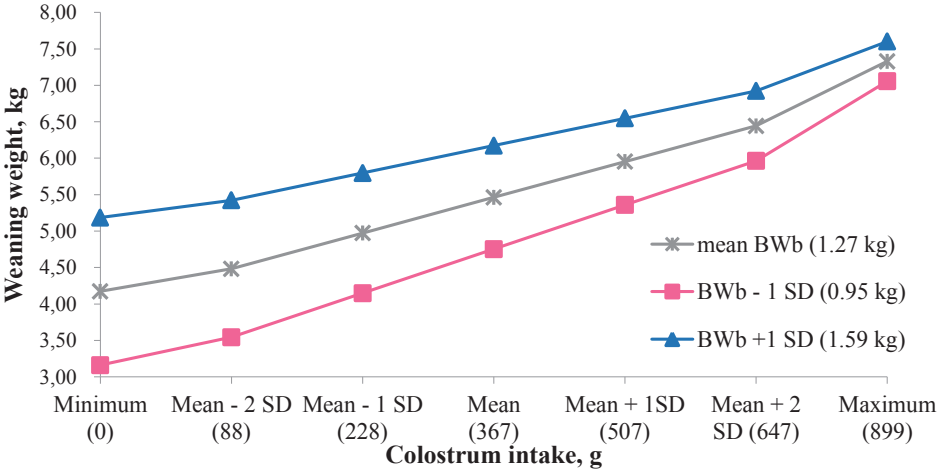

Figure 1. *Predicted weaning weights by colostrum intake for male Danbred piglets with a mean interval between birth and first suckling. The positive association between colostrum intake and weaning weight was more pronounced in low birth weights piglets as weaning weight increased steeper with higher colostrum intake in low versus high birth weights.*

Table 3. *Parameter estimates of the multivariable linear mixed model with weaning, intermediate and finishing weight as outcome variable*

	Weaning		Intermediate		Finishing	
	Estimate	*p-value*	Estimate	*p-value*	Estimate	*p-value*
Intercept[1]	4.17	*<0.001*	19.18	*<0.001*	73.02	*<0.001*
Colostrum intake, g	0.004	*<0.001*	0.010	*<0.001*	0.017	*<0.001*
Birth weight, kg	3.15	*<0.001*	9.03	*<0.001*	16.98	*<0.001*
Colostrum intake * birth weight	-0.003	*<0.001*	-0.009	*<0.001*	-0.015	*0.02*
Birth order	0.01	*0.01*	0.01	*0.01*	0.01	*0.01*
Sex						
Female	0.02	*0.71*	-0.07	*0.76*	-3.61	*<0.001*
Male	Ref.		Ref.		Ref.	
Breed						
Own crossbred landrace	0.79	*0.12*	-2.13	*0.002*	-1.87	*0.17*
PIC	0.22	*0.60*	1.27	*0.02*	8.16	*<0.001*
Topigs	0.36	*0.61*	2.61	*<0.001*	2.62	*0.005*
Hypor	0.32	*0.44*	2.44	*<0.001*	2.83	*0.007*
Danbred	Ref.		Ref.		Ref.	
Log t_{FS}, minutes	0.20	*0.02*	0.17	*0.61*	-0.05	*0.95*
Breed * t_{FS}						
Own crossbred landrace	-0.01	*0.56*	0.58	*0.33*	0.50	*0.75*
PIC	-0.40	*0.005*	-0.92	*0.08*	-1.16	*0.37*
Topigs	-0.52	*<0.001*	-0.48	*0.31*	1.10	*0.35*
Hypor	-0.02	*0.87*	0.01	*0.98*	0.87	*0.45*
Danbred	Ref.		Ref.		Ref.	

t_{FS} = the interval between birth and first suckling, minutes.

[1] The intercept represents a first born male Danbred piglet without colostrum intake, a mean birth weight and a mean interval between birth and first suckling.

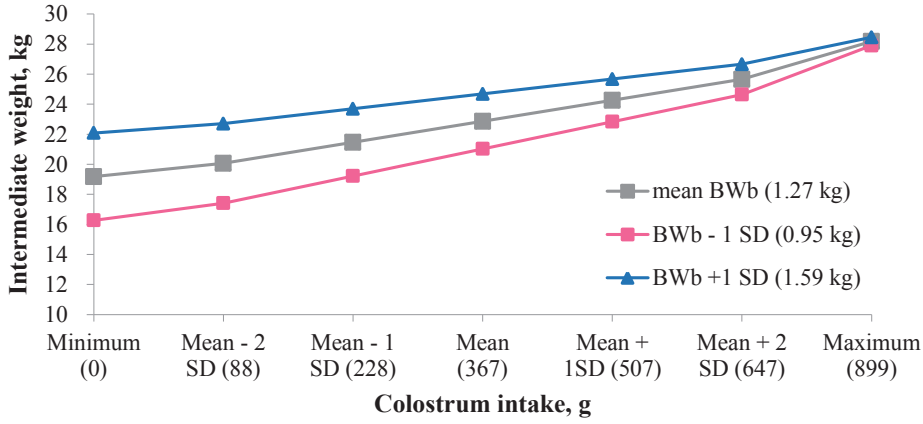

Figure 2. *Predicted intermediate weights by colostrum intake for male Danbred piglets with a mean interval between birth and first suckling. The positive association between colostrum intake and weaning weight was more pronounced in low birth weights piglets as weaning weight increased steeper with higher colostrum intake in low versus high birth weights.*

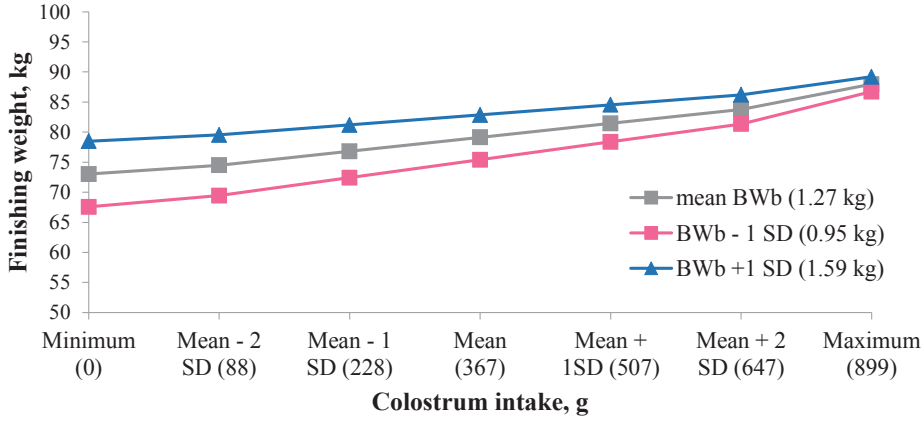

Figure 3. *Predicted finishing weights by colostrum intake for male Danbred piglets with a mean interval between birth and first suckling. The positive association between colostrum intake and finishing weight was more pronounced in low birth weights piglets as finishing weight increased steeper with higher colostrum intake in low versus high birth weights.*

Mortality analysis

Preweaning mortality. Based on univariable analyses, colostrum intake ($P < 0.001$), birth weight ($P < 0.001$), sex ($P = 0.17$), and log(t_{FS}) ($P < 0.001$) were related to preweaning mortality at the $P < 0.25$ significance level and hence, they were considered for further analysis. In contrast, birth order ($P = 0.37$) and breed ($P = 0.59$) were not withheld following univariable analyses. The multivariable model for preweaning mortality is shown in **Table 4**. To give a biological plausible interpretation to the intercept, birth weight and log(t_{FS}) were centered by subtracting the mean birth weight (1.27 kg) and the mean log t_{FS} (3.6), respectively. Hence, the intercept represents a piglet without colostrum intake, a mean birth weight and a mean t_{FS} having a predicted probability to die during suckling of 69% (95% CI 50; 82) (**Table 4**, **Figure 4**). Colostrum intake was negatively associated with the risk to die during the suckling period ($P < 0.001$). Considering piglets with a mean colostrum intake, a mean birth weight and a mean t_{FS}, the predicted probability of preweaning mortality dropped to 5% (95% CI 3; 8). Colostrum intake and birth weight were negatively interacted ($P < 0.0001$). As illustrated by **Figure 4**, higher colostrum intake reduced preweaning mortality more in piglets with lower birth weights. Birth weight was also negatively associated with preweaning mortality ($P = 0.004$). Regarding piglets without colostrum intake and a mean t_{FS}, the probability of preweaning mortality was 14% lower for piglets weighing 1 SD (0.32 kg) more than the mean birth weight. Finally, piglets with a longer t_{FS} were more likely to die during the suckling period ($P < 0.001$). Considering piglets without colostrum intake and a mean birth weight, the predicted probability of preweaning mortality was 10% and 17% higher when t_{FS} lasted 2.7 and 7.4 min longer than the mean t_{FS}, respectively.

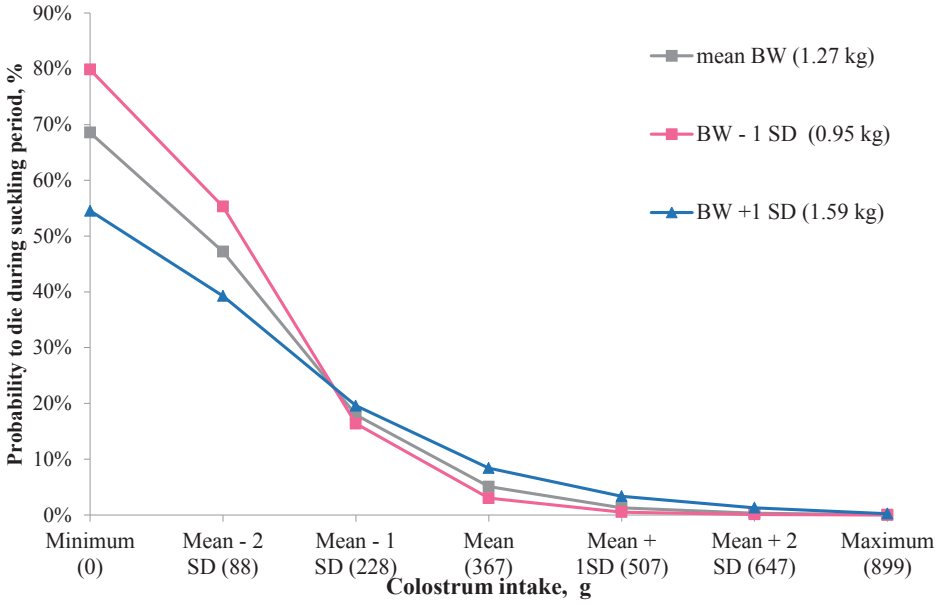

Figure 4. *Probabilities of preweaning mortality by colostrum intake. A piglet without colostrum intake, with a mean birth weight (BW_b) and a mean interval between birth and first suckling had a predicted probability to die during suckling of 69%. The negative association between colostrum intake and preweaning mortality was more pronounced in low birth weights piglets as mortality decreased steeper with higher colostrum intake in low versus high birth weights.*

Table 4. *Multivariable model with the probability of piglet mortality during the suckling period*

Parameter	Estimate	SE	Odds ratio (95% CI)	*P*
Intercept$_1$	0.78	0.39	-	0.08
Colostrum intake, g	-0.010	0.001	0.990 (0.988; 0.992)	< 0.001
Birth weight, kg	-1.86	0.65	0.16 (0.04; 0.56)	0.004
Colostrum intake * birth weight	0.010	0.002	1.010 (1.006; 1.013)	< 0.001
Log t_{FS}, minutes	0.52	0.15	1.68 (1.26; 2.23)	< 0.001

t_{FS} = the interval between birth and first suckling, minutes.

$_1$The intercept represents the logarithm of the odds to die during the suckling period for a piglet without colostrum intake, a mean birth weight and a mean t_{FS}.

Nursery mortality. Colostrum intake (P<0.001), birth weight (P<0.001), birth order (P=0.15) and log(t_{FS}) (P=0.005) were considered for further analysis, whereas sex (P=0.68) and breed (P=0.91) were excluded by univariable analyses. The multivariable model for nursery mortality is shown in **Table 5**. To give a biological plausible interpretation to the intercept, birth weight was centered by subtracting the mean birth weight (1.27 kg). Hence, the intercept represents a pig without colostrum intake, weighing the mean birth weight having a predicted probability to die during the nursery period of 18% (95% CI 6; 40) (**Table 5**, **Figure 5**). Colostrum intake was negatively associated with mortality at nursery (P=0.004). Regarding piglets with a mean colostrum intake and weighing the mean birth weight, the predicted probability to die at nursery dropped to 4% (95% CI 2; 8). Colostrum intake and birth weight were negatively interacted (P=0.008). As illustrated by **Figure 5**, higher colostrum intake reduced nursery mortality more in piglets with lower birth weights. Birth weight was also negatively associated with mortality at nursery (P=0.002). Regarding piglets without colostrum intake, the predicted probability to die at nursery was 10% lower for piglets weighing 1 SD (0.32 kg) more than the mean birth weight.

Mortality during the fattening period was not associated with colostrum intake, birth weight, birth order, sex, breed and t_{FS}. In order to explain mortality during the fattening period as good as possible, weaning and intermediate weight were included as additional parameters. Following univariable analysis piglets with higher weaning (P=0.04) and intermediate (P=0.006) weight were less likely to die during fattening.

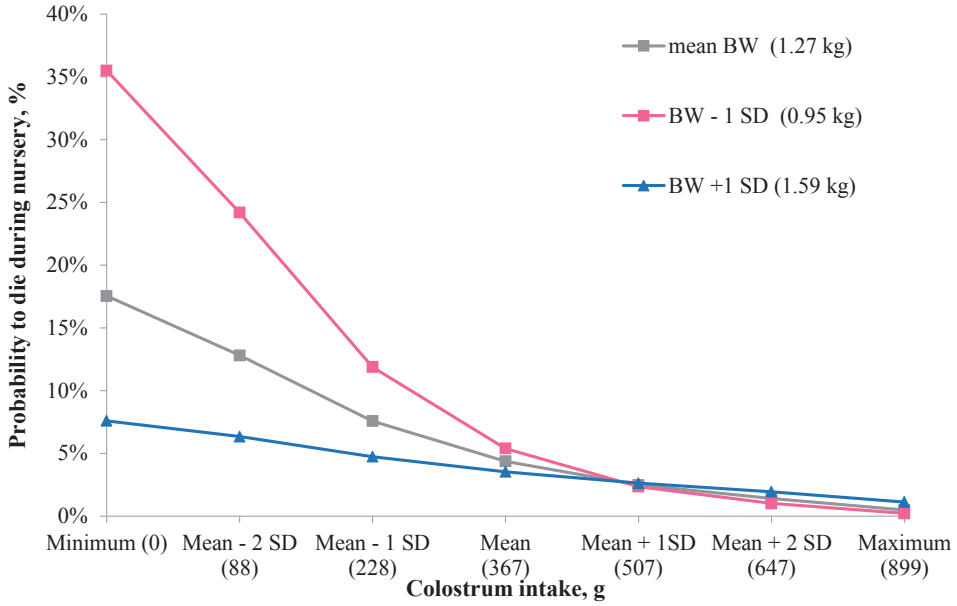

Figure 5. *Probabilities of mortality during the nursery period by colostrum intake. A piglet without colostrum intake and weighing the mean birth weight (BW_b) had a predicted probability to die at nursery of 18%. The negative association between colostrum intake and nursery mortality was strengthened for low birth weight piglets as mortality decreased steeper with higher colostrum intake in low versus high birth weights.*

Table 5. *Multivariable model with the probability of piglet mortality during the nursery period*

Parameter	Estimate	SE	Odds ratio (95% CI)	P
Intercept$_1$	-1.55	0.58	-	0.03
Colostrum intake, g	-0.004	0.001	0.996 (0.993; 0.999)	0.004
Birth weight, kg	-2.96	0.96	0.05 (0.01; 0.34)	0.002
Colostrum intake * birth weight	0.006	0.002	1.006 (1.002; 1.011)	0.008

$_1$The intercept represents the logarithm of the odds to die at nursery for a piglet without colostrum intake and a mean birth weight.

DISCUSSION

Performance and mortality in pigs is the result of complex interactions between numerous factors. To correct for confounding and clustering by herd and sow factors, statistic models included herd and sow as random factors. In the present study emphasis was given on colostrum intake, however birth weight, birth order, sex, breed and t_{FS} were also taken into account. In the present study physiologic measurements (*e.g.* IgG) were not performed and hence, only hypotheses about the underlying mechanisms for colostrum's influence are described. To our knowledge, this is the first study showing the long-term effects of colostrum intake on mortality and performance. Furthermore, the study was conducted on ten commercial herds and therefore the present results are of high practical relevance.

Descriptive results

Piglets' body weights were comparable with other studies where pigs were weighed at similar ages (*e.g.* De Grau et al., 2005; Larriestra et al., 2006; Fix et al., 2010). Preweaning mortality rate was 11.9%, which is consistent with mortality rates reported in other recent studies (*e.g.* Hales et al., 2013; Kirkden et al., 2013; Decaluwé et al., 2014). Mortality during the nursery was rather high in comparison to a nursery mortality rate of 2.8% in another study performed on 52 Belgian herds (Postma et al., 2015). The high overall nursery mortality might be

attributed to some farms as nursery mortality ranged from 0.9 to 18.3% (**Table 1**). The study by De Grau et al. (2005) was also conducted on different commercial farms and reported a similar mortality (range) during nursery and finishing.

Weight

Colostrum intake was positively associated with weaning, intermediate and finishing weight. Previous studies observed a positive relationship between colostrum intake and weight at weaning and/ or weight at six weeks of age (Decaluwé et al., 2014; Ferarri et al., 2014; Vallet et al., 2015). If colostrum intake was above 290 g per pig, body weight at six weeks of age was 2 kg heavier in the study by Devillers et al.(2011). The observed long-term positive associations with weight might be attributed to the fact that neonatal piglets with a high intake of colostrum (energy) are able to engage in teat fights and keep (regular) suckling and hence, initiate lactation more properly as milk removal is the best stimulator of lactation in sow (Hurley, 2001; Theil et al., 2006). High milk intake provides more nutrients to grow, but also a high level of lactogenic immunity. Colostral immunity is positively related with the development of active immunity (Damm et al., 2002; Le Dividich et al., 2005). Regarding immunity, piglets with a high colostrum and milk intake might be more competent and protected and thus, be less susceptible to (non-lethal) infections. Furthermore, colostrum and milk contain various bioactive compounds promoting gastro-intestinal development and nutrient absorption (Wang and Xu, 1996; Xu et al., 2000; Thymann et al., 2006). Many studies established the relation between birth weight and (lifetime) weight performance. Low birth weights have higher energy demands per kg of birth weight because of their higher surface-to-volume ratio (Noblet and Etienne, 1987), they have lower colostrum intake and remain stunted as they are less competitive at the udder and feed trough during lifetime (Quiniou et al., 2002; Johansen et al., 2004; Beaulieu et al., 2010; Paredes et al., 2012). The positive association between colostrum intake and weight performance varied according to birth weight as colostrum's beneficial effect was more pronounced if birth weight was decreased. This interaction is consistent with higher relative (colostral) energy demands per kg of birth weight in low birth weight piglets and implies that colostrum intake in low birth weight piglets should be favored by management (*e.g.* cross-fostering, colostrum supplements, placing at the udder) (Muns et al., 2015). The positive association between birth order and weight is hard to explain and needs further research. Sex affected only finishing

weight, which is consistent with the observation of a lower growth rate in females during the finishing period by Larriestra et al. (2006) and Paredes et al. (2012). The absence of any effect of sex and weaning and intermediate weight was also noted by other researchers (De Grau et al., 2005; Wolter et al., 2002; Douglas et al., 2013). Breed differences were observed as expected, given the moderate heritability of growth performance. In piglets from PIC and Topigs, a longer t_{FS} was associated with lower preweaning performance, which agrees with the findings of Decaluwé et al.(2014).

Mortality

Preweaning mortality. The observed negative association between colostrum intake and birth weight with preweaning mortality in the present study is consistent with other studies (*e.g.* Milligan et al., 2001; Quiniou et al., 2002; Farmer and Quesnel, 2009; Ferrari et al., 2014). It is well described that birth weight determines the ability to acquire colostrum (Cabrera et al., 2012; Panzardi et al., 2013), which is consistent with its major contribution to predict colostrum intake by Devillers et al. (2004) and Theil et al. (2014a). The observed interaction between colostrum intake and birth weight may confirm synergism among both predictors regarding preweaning survival. The probability of preweaning mortality decreased steeper with higher colostrum intake in lower birth weights, which might be due to the relative higher energy demands per kg of birth weight in small piglets. Hence, colostrum has a crucial role to piglets with low energy reserves at birth by supplying energy (Herpin et al., 2002; Le Dividich et al., 2005; Theil et al., 2014b). As piglets are born without immunity, colostrum may also enhance survival by passive transfer. However, insufficient immune transfer is not considered as a major cause of (early) preweaning losses (Varley et al., 1986; Le Dividich et al., 2005; Decaluwé et al., 2014). Birth order was not a determining factor for preweaning survival and this confirms previous studies (Le Dividich et al., 2005; Devillers et al., 2007; Cabrera et al., 2012). However, the results from some studies revealed decreased preweaning survival in piglets born late and attributed this to the fact that late born piglets have access to colostrum of lower IgG concentration (Klobasa et al., 2004) or to lowered vitality in these piglets (Tuchscherer et al., 2000; Rootwelt et al., 2012). The farrowing duration in this study population averaged 203 ± 115 min. There is little evidence that vitality would have been compromised in piglets born later and this might be the reason why birth order was not associated with preweaning mortality in the present study. The lack of an association can also

be attributed to the fact that preweaning mortality did not include piglets died on the first day of life. Sex was not associated with preweaning mortality, which is in agreement with the findings of Baxter et al.(2008). In contrast, other studies attributed a lower preweaning survival in males to their higher testosterone and cortisol levels (Larriestra et al., 2006), to surgical castration (Hales et al.,2013) or to impaired thermoregulation and greater susceptibility to mortality factors (Baxter et al., 2012). As preweaning survival is very variable, selection on this trait seems to be promising (Knol et al., 2002). However, breed was not associated with preweaning mortality, which is consistent with the low heritability for preweaning survival (Van Arendonk et al., 1996; Knol et al., 2002; Damgaard et al., 2003). The interval between birth and first suckling was positively associated with preweaning mortality, which is in accordance to literature (*e.g.* Tuscherer et al., 2000; Baxter et al., 2008; Vasdal et al., 2011; Panzardi et al., 2013). This interval is an important indicator of piglet vitality at birth (Tuchscherer et al., 2000; Baxter et al., 2008; Mota-Rojas et al., 2012). Vitality immediately after birth is the first factor influencing the consumption of colostrum by piglets. The ability to suckle colostrum soon after delivery increases the chance of survival by fulfilling the high energy demands of neonatal piglets (Edwards, 2002; Devillers et al., 2005; Alonso-Spilsbury et al., 2007; Quesnel et al., 2012). This observation can be applied in the farrowing managent by placing the (less vital) piglets at the udder (Andersen et al., 2009; Vasdal et al., 2011).

Mortality during the nursery period. Colostrum intake was negatively associated with mortality during the nursery period. Beyond the neonatal period, the supply of bio-active compounds and maternal immunity by colostrum is relatively more important to survive than the colostral energy supply (Varley et al., 1986; Xu et al., 2000; Le Dividich et al., 2005). Bio-active compounds of colostrum such as growth factors or lactoferrin and transferrin may affect mortality at nursery by promoting gut development function (Wang and Xu, 1996; Xu et al., 2000; Thymann et al., 2006) and protecting piglets to iron-dependent bacteria (Wagstrom and Zimmerman, 2000), respectively. Passive immunity is positively related with the development of active immunity (Damm et al., 2002; Le Dividich et al., 2005) and hence, a high level of passive immune transfer promotes indirectly resistance to infections, health and survival of the weaned pig (Varley et al., 1986; Le Dividich et al., 2005; Devillers et al., 2011). The relationship between colostrum intake and mortality in the nursery was assumed in other studies, however the present study investigated and confirmed this association for the first time. As earlier mentioned, further research is warranted to elucidate the underlying

mechanisms for our observations. Mortality in the nursery was also negatively associated with birth weight, which is consistent with the findings of De Grau et al.(2005) and Larriestra et al.(2006). As mentioned before, colostrum acquisition and hence, passive and indirectly active immunity, are determined by birth weight and may explain the negative association between birth weight and mortality in the nursery. Regarding mortality in the nursery period, colostrum management should also be optimized in favor of low birth weight piglets due to the negative interaction between colostrum intake and birth weight.

Mortality during the fattening period was only 1.5%. This low percentage might have resulted in a lack of power to observe any significant association.

CONCLUSION

Colostrum intake was positively associated with weaning, intermediate and finishing weight and negatively associated with mortality during the suckling and the nursery period. Hence, the present study clearly demonstrated the short-term as well as the long-term importance of colostrum intake on performance and mortality in commercial pig herds. Further research is needed to unravel the underlying mechanisms for colostrum's long-term beneficial impact. Emphasis was given on colostrum intake, however other determining factors were also considered as optimal pig production requires a multifactorial approach. Moreover, regarding the interactions between colostrum intake and birth weight, colostrum intake becomes especially crucial in low birth weight piglets. Being aware of these associations, colostrum management can be adjusted to optimize colostrum intake in order to maximize lifetime production potential in pigs.

LITERATURE CITED

- Alonso-Spilsbury, M, R. Ramírez-Necoechea, M. González-Lozano, D. Mota-Rojas, and M.E. Trujillo-Ortega. 2007. Journal of Animal and Veterinary Advances 6: 76-86.
- Andersen, I.L., I.A. Haukvik, and K.E. BØe. 2009. Drying and warming immediately after birth may reduce piglet mortality in loose-housed sows. Animal 3: 592-597.
- Baxter, E.M., S. Jarvis, R.B. D'Eath, D.W. Ross, S.K. Robson, M. Farish, I.M. Nevvison, A.B. Lawrence, and S.A. Edwards. 2008. Investigating the behavioural and physiological indicators of neonatal survival in pigs. Theriogenology 69: 773-783.
- Baxter, E.M., S. Jarvis, J. Palarea-Albaladejo, and S.A. Edwards. 2012. The weaker sex? The propensity for male-biased piglet mortality. Plos one 7.1.
- Beaulieu, A.D., J.L. Aalhus , N.H. Williams, J.F. Patience (2010). Impact of piglet birth weight, birth order, and litter size on subsequent growth performance, carcass quality, muscle composition, and eating quality of pork. J. Anim. Sci. 88: 2767-2778.
- Cabrera, R.A., X. Lin, J.M. Campbell and J. Odle. 2012. Influence of birth order, birth weight, colostrum and serum immunoglobulin G on neonatal piglet survival. Journal of Animal Science and Biotechnology 3: 42.
- Damgaard, L.H., L. Rydhmer, P. Lovendahl, and K. Grandinson. 2003. Genetic parameters for within-litter variation in piglet birth weight and change in within-litter variation during suckling. J. Anim. Sci. 81: 604-610.
- Damm, B.I., N.C. Friggens, J. Nielsen, K.L. Ingvarsten and, L.J. Pedersen. 2002. Factors affecting the transfer of porcine parvovirus antibodies from sow to piglets. Journal of Veterinary Medicine. A Physiology, Pathology, Clinical Medicine 49: 487-495.
- Decaluwé, R., D. Maes, I. Declerck, A. Cools, B. Wuyts, S. De Smet and G.P.J. Janssens. 2013. Changes in back fat thickness during late gestation predict colostrum yield in sows. Animal 7: 1999-2007.
- Decaluwé, R., D. Maes, B. Wuyts, A. Cools, S. Piepers, and G.P.J. Janssens. 2014. Piglets' colostrum intake associates with daily weight gain and survival until weaning. Livest Sci 162: 185-192.
- de Grau, A., C. Dewey, R. Friendship, and K. De Lange. 2005. Observational study of factors associated with nursery pig performance. The Canadian Journal of Veterinary Research 69: 241-245.

- Devillers N., C. Farmer, J. Le Dividich, and A. Prunier. 2007. Variability of colostrum yield and colostrum intake in pigs. Animal 1: 1033-1041.
- Devillers N., J. Le Dividich, C. Farmer, A.M. Mounier, M. Lefebvre, and A. Prunier. 2005. Origine et conséquences de la variabilité de la production par la truie et de la consommation de colostrum par les porcelets. J. Rech. Porcine 37: 435-442.
- Devillers N., J. Le Dividich, and A. Prunier. 2011. Influence of colostrum intake on piglet survival and immunity. Animal 5: 1605-1612.
- Devillers, N., J. van Milgen, A. Prunier, and J. Le Dividich. 2004. Estimation of colostrum intake in the neonatal pig. Anim. Sci.78: 305-313.
- Douglas, S.L., S.A. Edwards, E. Sutcliffe, P.W. Knap, and I. Kyriazakis. 2013. Identification of risk factors associated with poor lifetime growth performance in pigs. J. Anim. Sci. 91: 4123-4132.
- Edwards, S.A. 2002. Perinatal mortality in the pig: environmental or physiological solutions? Livest. Prod. Sci. 78: 3-12.
- Farmer, C. and H. Quesnel, 2009. Nutritional, hormonal and environmental effects on colostrum in sows. J. Anim. Sci. 87: 56-64.
- Ferrari, C.V., P.E. Sbardella, M.L. Bernardi, M.L. Coutinho, I.S. Vaz Jr., I. Wentz, and F.P. Bortolozzo. 2014. Effect of birth weight and colostrum intake on mortality and performance of piglets after cross-fostering in sows of different parities. Preventive Veterinary Medicine 114: 259-266.
- Fix, J.S., J.P. Cassady, W.O. Herring, J.W. Holl, M.S. Culbertson, M.T. See. 2010. Effect of piglet birth weight on body weight, growth, backfat, and longissimus muscle area of commercial market swine. Livestock Science 127: 51-59.
- Hales, J., V.A. Moustsen, M.B.F. Nielsen, and C.F. Hansen. 2013. Individual physical characteristics of neonatal piglets affected preweaning survival of piglets born in a noncrated system. J. Anim. Sci. 91: 4991-5003.
- Herpin, P., M. Damon, and, J. Le Dividich. 2002. Development of thermoregulation and neonatal survival in pigs. Livest. Prod. Sci. 78: 25-45.
- Herpin P., I. Louveau I., M. Damon, and J. Le Dividich. 2005. Environmental and hormonal regulation of energy metabolism in early development of the pig. In: Burrin D.G., and Mersmann H., editors, Biology of metabolism in growing animals. Elsevier, New York p. 345-374.
- Hurley, W. 2001. Mammary gland growth in the lactating sow. Livest. Prod. Sci. 70: 149-157.

- Johansen, M., Alban L., Kjærsgård, and M. Bækbo. 2004. Factors associated with suckling piglet average daily gain. Preventive Veterinary Medicine 63: 91-102.
- Kirkden, R.D., D.M. Broom, and I.L. Andersen. 2013. Invited Review: Piglet mortality: Management solutions. J. Anim. Sci. 91: 3361-3389.
- Klobasa, F., C. Schröder, C. Stroot,, and M. Henning. 2004. Passive immunisation in neonatal piglets in natural rearing- effect of birth order, birht weight, litter size and parity. Berliner und Munchener Tierarztliche Wochenschrift 117: 19-23.
- Knol, E.F., J.I. Leenhouwers, and T. van der Lende. 2002. Genetic aspects of piglet surival. Livest. Prod. Sci. 78: 47-55.
- Larriestra, A.J., S. Wattanaphansak, E.J. Neumann, J. Bradford, R.B. Morrison, and J. Deen. 2006. Pig characteristics associated with mortality and light exit weight for the nursery phase. Can. Vet. J. 47: 560-566.
- Le Dividich J., J.A. Rooke, and P. Herpin. 2005. Nutritional and immunological importance of colostrum for the new-born pig. J. Agric. Sci. 143: 469-485.
- Muns, R., X. Manteca, and J. Gasa. 2015. Effects of different management techniques to enhance colostrum intake on piglets' growth and mortality. Animal Welfare 24: 185-192.
- Milligan, B.N., D. Fraser, and D.L. Kramer. 2001. Birth weight variation in the domestic pig: effects on offspring survival, weight gain and suckling behavior. Applied Animal Behaviour Science 73: 179-191.
- Mota-Rojas, D., J. Martinez-Burnes, D. Villanue-Garcia, P. Roldan-Santiago, M.E. Trujillo-Ortega, H. Orozco-Gregorio, H. Bonilla-Jaime, and A. Lopez-Mayagoitia. 2012. Animal welfare in the newborn piglet: a review. Vet Med 57: 338-349.
- Noblet, J., and M. Etienne. 1987. Body composition, metabolic rate and utilization of milk nutrients in suckling piglets. Reprod.Nutr.Dev.27: 829–839.
- Noordhuizen, J. P. T. M., K. Frankena, M. V. Thrusfield, and E. A. M. Graat. 2001. Application of quantitative methods in veterinary epidemiology. Wageningen Pers, Wageningen, The Netherlands.
- Panzardi, A., M.L. Bernardi, A.P. Mellagi, T. Bierhals, F.P. Bortolozzo, and I. Wentz. 2013. Newborn piglet traits associated with survival and growth performance until weaning. Preventive Veterinary Medicine 110: 206-213.
- Paredes, S.P., A.J.M. jansman, M.W.A. Verstegen, A. Awati, W. Buist, L.A. den Harotg, H.M.J. van Hees, N. Quiniou, W.H. Hendriks, and W.J.J. Gerrits. 2012.

Analysis of factors to predict piglet body weight at the end of the nursery phase. J. Anim. Sci. 90: 3243-3251.

- Postma, M., A. Backhans, L. Collineau, S. Loesken, M. Sjölund, C. Belloc, U. Emanuelson, E. Grosse Beilage, K.D.C. Stärk, and J. Dewulf. 2015. The biosecurity status and its association with production and management characteristics in farrow-to-finish pig herds. Animal.
- Quesnel, H., C. Farmer, and N. Devillers. 2012. Colostrum intake: influence on piglet performance and factors of variation. Livest Sci 146: 105-114.
- Quiniou, N., J. Dagorn, and D. Gaudré. 2002. Variation of piglets' birth weight and consequences on subsequent performance. Livest. Prod. Sci. 78: 63-70.
- Rooke, J.A., and I.M. Bland. 2002. The acquisition of passive immunity in the newborn piglet. Livest. Prod. Sci. 78: 13-23.
- Rootwelt, V., O. Reksen, W. Farstad, and T. Framstad. 2012. Blood variables and body weight gain on the first day of life in crossbred pigs and importance for survival. J. Anim. Sci. 90: 1134-1141.
- Theil, P.K., C. Flummer, W.L. Hurley, N.B. Kristensen, R.L. Labouriau, and M.T. Sorensen. 2014a. Mechanistic model to predict colostrum intake based on deuterium oxide dilution technique data and impact of gestation and prefarrowing diets on piglet intake and sow yield of colostrum. J. Anim. Sci 92: 5507-5519.
- Theil, P.K., C. Lauridsen, and H. Quesnel. 2014b. Neonatal piglet survival: Impact of sow nutrition around parturition on fetal glycogen deposition and production and composition of colostrum and transient milk. Animal 8: 1021-1030.
- Theil, P.K., K. Sejrsen, W.L. Hurley, R. Labouriau, B. Thomsen, and M.T. Sorensen. 2006. Role of suckling in regulating cell turnover and onset and maintenance of lactation in individual mammary glands of sows. J. Anim. Sci. 84: 1691-1698.
- Thymann, T., D.G. Burrin, K.A. Tappenden, C.R. Bjornvaad, S.K. Jensen, and P.T. Sangild. 2006. Formula-feeding reduces lactose digestive capacity in neonatal pigs. Br. J. Nutr. 95: 1075-1081.
- Tuchscherer, M., B. Puppe, A. Tuchscherer, and U. Tiemann. 2000. Early identification of neonates at risk: traits of newborn piglets with respect to survival. Theriogenology 54: 371-388.
- Van Arendonk, J.A.M, C. van Rosmeulen, L.L.G. Janss, and E.F. Knol. 1996. Estimation of direct and maternal genetic (co)-variances for survival within litters of piglets. Livest. Prod. Sci. 46: 163-171.

- Vallet, J.L., J.R. Miles, L.A. Rempel, D.J. Nonneman, and C.A. Lents. 2015. Relationships between day one piglet serum immunoglobulin immunocrit and subsequent growth, puberty attainment, litter size, and lactation performance. J. Anim. Sci. 93: 2722-2729.
- Varley, M.A., A. Maitland, and A. Towle. 1986. Artificial rearing of piglets: the administration of two sources of immunoglobulins after birth. Anim. Prod. 43: 121-126.
- Vasdal, G., I. Østensen, M. Melišová, and, B. Bozděchová. 2011. Management routines at the time of farrowing-effects on teat success and postnatal piglet mortality from loose housed sows. Livestock Science 136: 225-231.
- Wagstrom, E.A., and J.J. Zimmerman. 2000. Immune components in porcine mammary secretions. Viral Immunology 13: 383-397.
- Wang, T., and R. J. Xu. 1996. Effects of colostrum feeding on intestinal development in newborn pigs. Biol. Neonate 70: 339-348.
- Wolter, B.F., M. Ellis, B.P. Corrigan, and J.M. DeDecker. 2002. The effect of birth weight and feeding of supplemental milk replacer to piglets during lactation on preweaning and postweaning growth performance and carcass characteristics. J. Anim. Sci. 80: 301-308.
- Xu, R.J., F. Wang, S.H. Zhang. 2000. Postnatal adaptation of the gastrointestinal tract in neonatal pigs: a possible role of milk-borne growth factors. Livest. Prod. Sci. 66: 95-107.

Chapter 4

Sow and litter factors influencing colostrum yield and nutritional composition

I. Declerck, J. Dewulf, S. Piepers, R. Decaluwé, and D. Maes

Journal of Animal Science (2015) 93: 1309-1317.

IV. SOW AND LITTER FACTORS INFLUENCING COLOSTRUM YIELD AND NUTRITIONAL COMPOSITION

ABSTRACT

One of the main characteristics of colostrum intake, yield and composition in pigs is its variability. The present observational study aimed to investigate factors influencing colostrum yield and composition in ten commercial herds. In total 100 sows of five different breeds and their 1,455 live-born piglets were included. Sows' colostrum yield was estimated by the colostrum intake of their suckling piglets. Colostrum composition was analyzed by LactoScope Fourier transform infrared spectroscopy. Colostrum yield averaged 3,500 ± 110 g, the percentage of colostral fat, protein and lactose in colostrum averaged 5.39 ± 0.12, 16.49 ± 0.14 and 2.02 ± 0.05, respectively. The effect of sow, litter and parturition factors on colostrum yield and composition were evaluated with a linear mixed regression model with herd included as a random factor. Sows with a gestation length of 113 days had a higher colostrum yield (4,178 ± 506 g) than sows with a gestation length of 114-115 days (3,342 ± 107 g) ($P = 0.04$). An interaction was found between the litter birth weight of the suckling piglets (**LW_{SP}**) and gestation length ($P = 0.03$). In sows with a gestation length of 114 and 115 days colostrum yield increased with higher LW_{SP} ($P = 0.009$). A shorter interval between birth and first suckling of the litter was related with a higher colostrum yield ($P < 0.01$). The percentage of colostral fat was higher in Hypor sows (6.35 ± 0.51) than in PIC (4.98 ± 0.27) ($P = 0.001$), Topigs (5.05 ± 0.14) ($P < 0.001$) and Danbred (5.34 ± 0.22) ($P < 0.001$) sows. The percentage of colostral fat was negatively associated with parity ($P = 0.02$) and positively associated with the number of live-born piglets ($P = 0.03$). The percentage of colostral protein and lactose were not significantly associated with any factor in the multivariable model. In conclusion, this study demonstrated that colostrum yield and colostral fat are affected by different sow and litter factors. Pig producers may implement these observations in their management to maximize production and reproduction potential by optimizing colostrum intake, yield and composition.

Key words: breed, colostrum, composition, interval between birth and first suckling, sow, yield

INTRODUCTION

Colostrum intake by piglets is crucial during the whole lifetime (de Passillé and Rushen, 1989; Edwards et al., 2000; Tuschscherer et al., 2000; Devillers et al., 2011; Decaluwé et al., 2014). Colostrum supplies energy, maternal immunity and growth factors (Xu et al., 2000; Rooke and Bland, 2002; Herpin et al., 2005). During the first days of life, sufficient energy supply is crucial to survive as piglets' energy reserves at birth are too low (Mellor and Cockburn, 1986; Le Dividich et al., 1994) compared to the demands (Le Dividich et al., 2005; Theil et al., 2014). Colostrum, especially colostral fat, is an efficient energy source to neonatal piglets (Herpin et al., 1992; Le Dividich et al., 1994). Beyond the neonatal period, the supply of maternal immunity by colostrum is relatively more important to survive than the supply of energy (Varley et al., 1986; Le Dividich et al., 2005). In the current context of reducing antibiotics, sows can be vaccinated to protect their litters against some diseases through maternal immunity. However, good maternal immunity can only be achieved by an adequate colostrum intake by the piglets (Rooke and Bland, 2002; Farmer and Quesnel, 2009; Quesnel et al., 2012). Optimization of colostrum intake, yield and composition is therefore of utmost importance to survival and good performance of the piglets.

As colostrum yield has been shown to be independent of the litter size, a higher number of live-born piglets per litter resulted in a lower colostrum intake per piglet (Devillers et al., 2007). In addition to the problem of insufficient colostrum production by the sow, there is also a huge variation in colostrum yield and composition between sows (Le Dividich et al., 2005; Farmer and Quesnel, 2009; Quesnel, 2011). Little information is available on factors that potentially can affect the colostrum yield and composition on commercial pig farms. Therefore, the objective of this study was to investigate whether and to what extent sow, litter and parturition factors influence colostrum yield and composition of sows across different herds despite herd-specific policy.

MATERIALS AND METHODS

Study population and animal handling

The study was approved by the Ethical Committee of the Faculty of Veterinary Medicine, Ghent University (EC2011/085) and was performed at ten different commercial pig herds in Flanders (northern Belgium). Herds were selected based on willingness of the farmer to cooperate, insemination with semen from Pietrain boars and on sow breeding lines. On each farm only one sow breeding line was presented. Five different breeds were included: one own Crossbred landrace and four commercial crossbred sows (PIC, Topigs, Hypor and Danbred). The breeding lines PIC, Hypor and Danbred were present on two farms, whereas own Crossbred landrace and Topigs were present at one or three herds, respectively. Within a herd, ten sows were selected based on occurrence of farrowing during the stay of the first author at the herd. No restriction on parity nor on gestation length of the sows was imposed, but it was taken into account that parity and gestation length were uniformly distributed across the different herds and breeds. Farrowing induction was not allowed in the study sows. All parturitions were 24 h a day attended, but manual farrowing assistance by the first author was kept to a minimum. The management procedures routinely used for the periparturient sows (*e.g.* farrowing supervision) on the farms were maintained as much as possible. Manual extraction of piglets or injection with oxytocin performed by the pig producer was registered. When a piglet was born, the back was dried with a paper towel, an ear tag was placed in the right ear, the birth weight was measured and the birth rank number was marked on the back. Thereafter, piglets were placed back on the place where they were taken (mostly at the sows' vulva). Furthermore, time of birth and time of first suckling was registered for each piglet. Cross fostering of piglets was not allowed before the second day of life.

Calculations and definitions

Sows' colostrum yield between the onset of parturition and 24 h thereafter was estimated as the sum of the colostrum intake by their suckling piglets. Colostrum intake was estimated by a regression equation as described by Devillers et al. (2004), based on birth weight (BW_b), weight at 17 to 24 h of age (further mentioned as weight at 24 h, BW_{24}), time between birth and first suckling ($\mathbf{t_{FS,\ piglet}}$) and time elapsed from first suckling to time at BW_{24} (t). The

regression equation is as follows: -217.4 + 0.217t + 1,861,019 BW_{24}/t + BWb * (54.80-1,861,019/t) x (0.9985 – 3.7 *10-4 t_{FS}, piglet + 6.1 * 10-7 * t_{FS^2}, piglet). This equation is well adapted for studies on large numbers of animals in field conditions (Farmer et al., 2006). The accuracy of the scale was 0.02 kg. Negative colostrum intake was assumed to be zero in accordance with Devillers et al., 2007. Furthermore, the colostrum intake by piglets that died before BW_{24} was not taken into consideration as the estimation of colostrum intake by these piglets may be inaccurate (Devillers, 2004; Devillers et al., 2007; Quesnel, 2011). Piglets alive at BW24 are further referred as suckling piglets. Gestation was assumed to start at the day of first insemination (day 0) and day of parturition was assumed to be the last day of gestation. In the present study gestation length varied from 113 to 116 days and was categorized as 113 days (early parturition), 114-115 days (normal range) and 116 days (late parturition) based on literature (Vanderhaeghe et al., 2011). Parturition duration was calculated as the time interval between the birth of the first and the last piglet. A stillborn piglet was defined as a piglet with no signs of decay and found dead behind the sow. Litter uniformity was calculated as the coefficient of variation (%) for the birth weight of all piglets within a litter.

Colostrum sampling and analysis

Colostrum (15 mL) was collected at 3 h after the birth of the first piglet. Colostrum was collected across all teats on one side of the udder and without the use of oxytocin. From nine sows, an insufficient amount of colostrum could be collected for further analysis. From the remaining 91 sows, the nutritional composition of colostrum was determined. The colostrum samples were frozen at -20°C and stored until further processing. The fat, protein and lactose content were analyzed by Lactoscope FTIR Advanced type FTA-3.0 (Delta Instruments, Drachten, the Netherlands) as used by Decaluwé et al. (2013; 2014). Because of the high amount of sample needed, the analyses were not performed in duplicate. However, samples of 8 sows were also analysed by the Gerber and Kjeldahl method in order to determine the fat and protein content, respectively. All results were linearly corrected (R^2 between FTIR and Gerber = 0.9975; R^2 between FTIR and Kjeldahl = 0.9997).

Data processing and statistical analysis

The Kolmogorov-Smirnov test was used to check whether the variables were normally distributed. The dependent variables (colostrum yield, colostral fat, protein and lactose) were normally distributed. The independent variables parity, parturition duration, number of piglets born dead/ alive per litter, number of suckling piglets per litter and the interval between birth and first suckling of the litter were not normally distributed. Pearson correlation tests between the dependent variables were calculated. Results are reported as mean ± SEM or median ± interquartile range when variables were normally or not normally distributed, respectively. Range is marked between brackets. Statistical analyses were performed using SAS 9.4 (SAS Institute Inc., NC, USA). The associations between sow, litter and parturition factors on the one hand and colostrum yield and the percentage of colostral fat, protein and lactose on the other hand were investigated using linear mixed regression models. A random herd effect was included to correct for clustering of sows in the herd and to correct for confounding factors at the herd level. Initially, the association between the dependent variables (colostrum yield, colostral fat, protein and lactose) and each independent variable was evaluated using univariable linear mixed regression models. Statistical significance in this step was assessed at $P < 0.20$. Second, Pearson or Spearman rank correlation tests, for either normally or not normally distributed independent variables, respectively, were calculated among the significant independent variables to avoid multicollinearity in the next steps. If the absolute value of the correlation coefficient between two selected independent variables was higher than 0.60, the one with the highest statistical significance was withheld for further analysis. Based on this, the litter birth weight of the suckling piglets was selected instead of the litter birth weight of the live-born piglets. Then, the remaining independent variables were used to build a multivariable linear regression model by a manual stepwise backward model building procedure. Statistical significance in this step was assessed at $P < 0.05$. Finally, all 2-way interactions were tested and removed when non-significant ($P > 0.05$). Normal probability plots of residuals and plots of residuals versus predicted values were generated to check whether the assumptions of normality and homogeneity of variance had been fulfilled. Influence of outliers was tested through Cook's distance, DFFITS and DFBETAS. No influential cases were found. Considering categorical independent variables, planned comparisons between categories were evaluated with the LSD post-hoc test. Because of pairwise comparisons, a Bonferroni correction was applied. In the multivariable model colostral protein and colostral lactose were not significantly associated with any factor. The

variance components of colostrum yield and colostral fat were estimated at the herd and the sow level. The correlation coefficient (r) between on the one hand colostrum yield and colostral fat and on the other hand the independent variables was calculated using the coefficient of determination (R^2) from the mixed regression model. The r was calculated as the square root of r^2, the latter representing the ratio of the variability in colostrum yield and colostral fat directly attributable to the variability in the independent variables (model sum of squares, SSM) over the total remaining variability in colostrum yield and colostral fat (total sum of squared differences, SST) [$r^2 = SSM / SST$] (Dohoo et al., 2009).

RESULTS

Descriptive results

In total, 100 sows with 1,455 live-born and 110 stillborn piglets were included. Colostrum intake of 1,371 suckling piglets was used to calculate sows' colostrum yield. The negative colostrum intake of 159 piglets was considered as being zero. Colostrum intake per suckling piglet was 268 ± 10 g (36 to 577 g). Colostrum yield per sow was 3,500 ± 110 g (653 to 7 498 g). Fifty-four percent of the sows produced less than 250 g colostrum per live-born piglet, the recommended amount to achieve survival and good performance (Quesnel et al., 2012). The colostral fat, protein and lactose concentrations were 5.39 ± 0.12 (2.88 to 8.41%), 16.49 ± 0.14 (13.77 to 20.80%) and 2.02 ± 0.05 (0.81 to 2.82%), respectively. Descriptive data of the independent sow, litter and parturition variables are presented in **Table 1** (continuous variables) and **Table 2** and **Table 3** (categorical variables).

Table 1 *Descriptive statistics of the different continuous variables obtained from 100 sows and their litters and the results of the univariable analyses with the continuous variables as independent variables and colostrum yield* ***(CY)****, the percentage of colostral fat* ***(CF)****, protein* ***(CPr)*** *and lactose* ***(CL)*** *as continuous dependent variables.*

Variable	Mean ± SEM	Range	P			
			CY, g	**CF**	**CPr**	**CL**
Parity*	3 ± 3	1 - 11	0.05	0.06	0.04	0.02
Parturition duration*, min	203 ± 115	75 - 716	0.19	0.45	0.73	0.97
Number of piglets born dead per litter*	1 ± 2	0 - 6	0.12	0.88	0.56	0.08
Number of piglets born alive per litter*	15 ± 4	7 - 22	0.83	0.06	0.81	0.27
Number of suckling piglets per litter*	14 ± 4	7 - 22	0.23	0.10	0.66	0.24
t_{FS}*	45 ± 34	16 - 163	0.003	0.94	0.83	0.63
Mean birth weight per piglet, kg						
Live-born piglets	1.3 ± 0.2	0.8 - 2	0.23	0.75	0.49	0.80
suckling piglets	1.3 ± 0.2	0.8 - 2	0.23	0.91	0.44	0.62
Litter birth weight, kg						
Live-born piglets	18.4 ± 4.3	5 - 29	0.07	0.20	0.63	0.47
suckling piglets	17.6 ± 4.0	10 - 29	0.04	0.11	0.60	0.60
Litter uniformity, %						
Live-born piglets	20 ± 6	4 - 35	0.93	0.31	0.92	0.85
suckling piglets	18 ± 6	4 - 32	0.97	0.26	0.99	0.95

t_{FS} = the interval between birth and first suckling of the litter, minutes.

*Mean ± SEM for normally or median ± interquartile range for not-normally (indicated by *) distributed variables. Stillborn piglets defined as piglets with no signs of decay and found dead behind the sow. Suckling piglets defined as live-born piglets still alive at 24 h of age.*

Table 2 *Descriptive statistics of the different categorical variables obtained from 100 sows and their litters and the results of the univariable analyses with the categorical variables as independent variables and colostrum yield as dependent variable.*

		Colostrum yield, g		
Variable	%	Mean	SEM	P
Breed				0.66
Crossbred landrace	10	3,367	295	
PIC	20	3,654	314	
Topigs	30	3,446	135	
Hypor	20	3,892	213	
Danbred	20	3,104	217	
Gestation length, days				0.06
113	9	4,178	506	
114-115	72	3,342	107	
116	19	3,781	234	
Use of oxytocin during farrowing				0.06
No	59	3,684	132	
Yes	41	3,236	154	
Manual help during farrowing				0.02
No	76	3,601	123	
Yes	24	3,180	157	
Presence of stillbirths				0.70
No	45	3,489	164	
Yes	55	3,509	130	

Table 3 *Descriptive statistics of the different categorical variables obtained from 91 sows and their litters and the results of the univariable analyses with the categorical variables as independent variables and the percentage of colostral fat* ***(CF)****, protein* ***(CPr)*** *and lactose* ***(CL)*** *as dependent variables.*

		Colostrum composition								
	%	Colostral fat			Colostral protein			Colostral lactose		
Variable		Mean	SEM	P	Mean	SEM	P	Mean	SEM	P
Breed				**<0.01**			0.40			**0.12**
Crossbred landrace	10	5.35	0.51		17.13	0.51		1.95	0.16	
PIC	16	4.98	0.27		16.29	0.25		2.27	0.01	
Topigs	28	5.05	0.14		16.79	0.28		2.03	0.01	
Hypor	18	6.35	0.24		16.11	0.30		1.87	0.12	
Danbred	19	5.34	0.22		16.25	0.40		1.98	0.10	
Gestation length, days				0.27			0.61			0.43
113	9	5.05	0.27		16.55	0.38		2.12	0.11	
114-115	64	5.43	0.14		16.62	0.18		1.99	0.06	
116	18	5.42	0.28		15.99	0.25		2.09	0.10	
Use of oxytocin during farrowing				0.80			0.22			**0.10**
No	55	5.42	0.16		16.35	0.17		2.09	0.06	
Yes	36	5.34	0.17		16.72	0.25		1.92	0.08	
Manual help during farrowing				0.32			0.67			0.86
No	69	5.41	0.14		16.46	0.16		2.02	0.05	
Yes	22	5.32	0.23		16.58	0.31		2.04	0.10	
Presence of stillbirths				0.25			**0.14**			**0.02**
No	39	5.53	0.19		16.70	0.25		1.90	0.08	
Yes	52	5.28	0.14		16.33	0.17		2.11	0.05	

Multivariable model

Colostrum yield and the percentage of colostral fat were not correlated (r = 0.006; P = 0.95). The results of multivariable mixed linear regression analyses and pairwise comparisons are summarized in **Table 4**.

Factors influencing colostrum yield. Sows with a gestation length of 113 days had a higher colostrum yield (4,178 ± 506 g) than sows with a gestation length of 114-115 days (3,342 ± 107 g) (P = 0.04). No significant differences were observed between the other gestation length categories by the LSD post-hoc test. An interaction between the litter birth weight of suckling piglets (**LW_{SP}**) and gestation length was observed (*P* = 0.03). In sows with a gestation length of 114-115 days colostrum yield increased with higher LW_{SP} (*P* = 0.009). Compared to sows with a gestation length of 116 days, colostrum yield of sows with a gestation length of 114-115 days increased with 148 g for each unit increase of LW_{SP} (*P* = 0.009). A shorter interval between birth and first suckling of the litter (**t_{FS}**) was related with a higher colostrum yield (*P* < 0.01). When t_{FS} lasted one minute longer, colostrum yield decreased with 11 g. Eighteen percent of the variation in colostrum yield between sows in the present study was explained by the final model. The relative contribution of gestation length, the interaction between LW_{SP} and gestation length and t_{FS} to the total explained variation was 26; 28 and 46% respectively.

Factors influencing colostrum composition. The percent fat in colostrum was associated with breeding line (*P* < 0.01). Hypor sows (6.35 ± 1.00) had a higher colostral fat than PIC (4.98 ± 1.07) (*P* < 0.01), Topigs (5.05 ± 1.36) (*P* < 0.01) and Danbred (5.34 ± 0.96) (*P* < 0.01). No other significant differences were observed between breeds. The percentage of colostral fat decreased with 0.11 (*P* = 0.02) for one parity increase. Finally colostral fat increased by 0.09 if a sow had one extra live-born piglet (*P* = 0.03). The multivariable model explained 26 % of the variation of colostral fat. The effect of breed accounted for 69% of the total explained variation. The relative contribution of parity and number of live-born piglets in the total explained variation was 17 and 14%, respectively. In the multivariable model colostral protein and lactose were not significantly associated with any factor.

Table 4 *Final results of multivariable mixed linear regression analyses and pairwise comparisons with colostrum yield (n = 100) and colostral fat (n = 91) as dependent variables.*

Variable	Independent Variable	Slope	SE	LSM	P for overall effect
Colostrum yield, g	**Intercept**	5,656	1,034	…	<0.001
	GL				0.026
	113	-2,895	1,599	4,233[a]	
	114-115	-3,040	1,110	3,374[b]	
	116	Ref.	…	3,807	
	t_{FS}	-11	3.66	…	0.004
	LW_{SP}	-74	52	…	0.229
	GL * LW_{SP}				0.031
	113	188	91	…	
	114-115	148	58	…	
	116	Ref.	…	…	
Colostral fat, %	**Intercept**	4.31	0.70	…	<0.001
	Breed				<0.001
	Crossbred landrace	0.39	0.41	5.50	
	PIC	-0.02	0.36	5.09[a]	
	Topigs 20	-0.01	0.30	5.00[a]	
	Hypor	1.38	0.34	6.50[b]	
	Danbred	Ref.	…	5.11[a]	
	Parity	-0.11	0.05	…	0.015
	Number live born piglets	0.09	0.04	…	0.026

GL = gestation length, days.

t_{FS} = the interval between birth and first suckling of the litter, minutes.

LW_{SP} = the litter birth weight of SP, kilogram.

*GL * LW_{SP} = interaction between GL and LW_{SP}*

SP = suckling piglets defined as live-born piglets still alive at 24 h of age.

LSM = Least Squares Means, evaluated at the mean t_{FS} and the mean LW_{SP}. Bonferroni correction was applied to adjust for pairwise comparisons. LSM with different superscripts between categories of one independent variable differ (P < 0.05)

DISCUSSION

Sows' colostrum yield and composition in this study was consistent with results from previous studies (Klobasa et al., 1987; Devillers et al., 2007; Farmer et al., 2007; Foisnet et al., 2010; Quesnel et al., 2012; Decaluwé et al., 2013). The present study was performed on ten commercial farms with five different breeding lines to maximize external validity, which is in contrast to previous studies all conducted on one farm with one breeding line (Devillers et al., 2007; Foisnet et al., 2011; Decaluwé et al., 2013). Furthermore, this study was able to investigate the effect of (natural) gestation length across different parities, in contrast to studies performing parturition induction (Devillers et al., 2007; Quesnel et al., 2011) or including only primiparous sows (Foisnet et al., 2010; 2011). Finally, time to first suckling was individually recorded instead of standardizing this interval at 30 min (Devillers et al., 2007; Quesnel, 2011) and in the present study piglets were not placed on the udder if time to first suckling took longer than 40 (Quesnel, 2011) or 60 (Foisnet et al., 2010) min.

Colostrum yield

Sow factors. Colostrum yield might have some breed component (Le Dividich et al., 2005; Farmer and Quesnel, 2009). In the present study no significant association between colostrum yield and breeding line was observed. Further research which includes more different breeds is needed to exclude a breed effect on colostrum yield. Nor was colostrum yield affected by parity, corresponding with earlier results (Le Dividich et al., 2005; Quesnel, 2011). Devillers et al. (2007) observed that second and third parity sows tended to have a higher colostrum yield than other parities. Decaluwé et al. (2013) found that first to third parity sows had a significantly higher colostrum yield than higher parity sows. The latter study also observed a longer gestation length in younger sows and a positive correlation of colostrum yield and gestation length, whereas in the present study sows with a gestation length of 113 days produced more colostrum than sows with a gestation length of 114-115 days. Decaluwé et al. (2013) assumed that the positive relationship between colostrum yield and gestation length was due to a decreased vitality of the piglets in earlier parturitions, however they did not observe differences in the interval between birth and first suckling between piglets born before and after day 114 of gestation. In accordance to the present study, Devillers et al. (2007) found a negative relationship between colostrum yield and gestation length. Nevertheless they could not ascertain if this negative relationship was due to gestation length

or to parturition induction as sows farrowing after 114 days of gestation were induced. In most previous studies, the effect of gestation length on colostrum yield might have been confounded by parturition induction (Devillers et al., 2007; 2011; Quesnel, 2011). Low colostrum yield is related with delayed hormonal changes before parturition (Foisnet et al. (2010). As progesterone is the main factor determining gestation length (Senger, 2005), we may wonder if the observed relationship between colostrum yield and gestation length might be due to differences in hormonal balance of sows with different gestation length. Hence, further research is needed to elucidate the relationship between maternal hormones, colostrum yield and gestation length in sows farrowing naturally across different gestation lengths and parities.

Litter factors. Colostrum yield was not significantly affected by litter size. This observation is in accordance with all previous studies (Devillers et al., 2005; Le Dividich et al., 2005; Devillers et al., 2007; Farmer and Quesnel, 2009; Foisnet et al., 2010; Quesnel, 2011; Decaluwé et al., 2014). No significant association between average birth weight of the litter and colostrum yield was found. Most studies did not observe a relationship between litter birth weight and colostrum yield (Le Dividich et al., 2005; Devillers et al., 2007; Farmer and Quesnel, 2009; Foisnet et al., 2010; Quesnel, 2011). In the present study, an interaction between LW_{SP} and gestation length was observed. The significant positive relation between LW_{SP} and colostrum yield of sows with a gestation length of 114-115 days is consistent with the observation of Devillers et al. (2005) that sows with high colostrum yield were found to have heavier litters at birth. In the present study, the lack of relation between gestation length and LW_{SP} for sows with a gestation length of 113 or 116 days might be attributed to the lower number of sows in these categories. To elucidate the interaction and to clearly determine the effect of litter birth weight on colostrum yield, a uniform distribution of sows across (more) gestation lengths is needed. Farmer et al. (2006) suggested that variation of piglet birth weight within a litter is (positively) related with colostrum yield, however this was not observed in the present study. In previous studies, the interval between birth and first suckling was usually between 10 and 30 min (de Passillé and Rushen, 1989; Le Dividich et al., 2005; Foisnet et al., 2010; Decaluwé et al., 2013). In the present study, t_{FS} was 45 ± 34 min (16 to 163). Some studies estimated this interval at 30 min instead of recording t_{FS} for each individual piglet as an error of 15 min in t_{FS}, piglet induces an average error in the regression equation for colostrum intake of approximately 6g/kg (Devillers et al., 2004;

2007). Other studies recorded the interval for each individual piglet and when it exceeded 40 (Foisnet et al., 2011) or 60 min (Foisnet et al., 2010), piglets were placed on the udder. In the present study the interval between birth and first suckling was recorded for each piglet and piglets were not placed on the udder by the first author nor by the pig producer. When t_{FS} increased with one minute, colostrum yield decreased with 11 g. This is consistent with the negative correlation between t_{FS} and litter birth weight gain observed by Foisnet et al. (2010). Some studies reported that the influence of suckling plays no role on colostrum yield as colostrum is produced during late gestation (Theil et al., 2012). Nevertheless, appropriate stimulation of the udder by piglets during the first day is believed to be important to elicit maximum colostrum yield and initiate lactation (Fraser, 1984; Theil et al., 2006). Moreover, the interval between birth and first suckling is an important indicator of piglet vitality at birth (Tuchscherer et al., 2000; Baxter et al., 2008; Mota-Rojas et al., 2012). As sows' colostrum yield was estimated by the intake of colostrum by their piglets, it is clear that colostrum yield depends on the ability of the piglets to reach and extract colostrum from the udder in addition to the ability of the sow to produce colostrum (Le Dividich et al., 2005; Devillers et al., 2007). In the present study, t_{FS} was a major determinant for colostrum yield, explaining 46% of the total explained variation in colostrum yield between sows.

Parturition factors. None of the parturition-related factors was significantly associated with colostrum yield. The lack of an effect of parturition duration and intervention on colostrum yield agrees with previous findings (Devillers et al., 2007; Foisnet et al., 2010; Quesnel, 2011). In contrast to Quesnel (2011), neither a (negative) relation between number of stillborn piglets or stillbirth and colostrum yield was observed. Despite the similar stillbirth rate of both studies, they are hard to compare as most farrowings were induced on day 113 in Quesnel (2011) and gestation length was related with colostrum yield in the present study.

Colostral fat

Sow factors. Fahmy (1972) suggested that sows from different breeds differ in colostrum composition. Zou et al. (1992) reported that CF was significantly higher in Meishan sows than US breeds. Farmer et al. (2007) observed no significant differences of colostral fat between Belgian Landrace/Pietrain, Duroc, Landrace and Yorkshire. The present study observed a significant difference of colostral fat between breeding lines. The percentage of fat in

colostrum was significantly higher in Hypor than in PIC, Topigs20 and Danbred sows. In the present study the observed difference in colostral fat between breeds is probably not due to a dilution effect as in cattle (Guy et al., 1994), because colostrum yield was not significantly affected by breed and no correlation between colostrum yield and colostral fat was found in the present study. The observed effect of breed on colostral fat suggests that selection strategies on colostral fat are possible. Furthermore colostral fat was significantly associated with parity as it decreased with 0.11% per parity increase. It is important to consider that parity was similarly distributed across the different breeds in the present study. Colostral fat originates from de novo synthesis in the mammary gland, diet and from body fat (Boyd and Kensinger, 1998). We may wonder whether the observed differences in colostral fat across different breeds and parities are due to differences in back fat thickness as fat reserves are breed specific and decline as parity progresses (Maes et al., 2004). No significant relationship between colostral fat and gestation length was observed in the present study. A decrease of colostral fat was observed if parturition was induced before day 113 of gestation (Jackson et al., 1995), but gestation length ranged from 113 to 116 days in the present study.

Litter and parturition factors. The percentage of colostral fat increased with 0.09 per extra piglet that was live-born. This (moderate) effect disagrees with the findings of Klobasa et al. (1987), who reported the lack of influence of litter size on colostrum composition. Furthermore, no influence of average birth weight, litter weight, litter uniformity, nor t_{FS} was observed in the present study. It is hard to compare our results with previous studies as none study reported (the lack of) the effect of these latter factors. Finally, the association with parturition-related factors such as parturition duration, injection of oxytocin, manual extraction or stillbirth, was not investigated in previous studies. In the present study not any of the studied parturition-related factors were related with colostral fat.

Colostral protein and lactose

In the univariable model colostral fat and parity were negatively related, whereas a positive association between colostral lactose and stillbirth and parity was observed. In the multivariable model colostral protein and lactose were not significantly associated with any factor. Hence, the (univariable) relations between colostral protein and fat with sow and litter factors will not further be discussed. We may wonder whether the lack of any relation with

colostral protein might be due to the fact that colostrum was collected at three hours after the birth of the first piglet. At that time point, immunoglobulins represent most of the total colostral protein. Immunoglobulin concentrations in colostrum vary too much between individual sows to identify significant differences (Klobasa and Butler, 1987), which corroborates with the present findings. Lactose is the least variable component of colostrum and varies only within a narrow range. Earlier studies reported the difficulty to affect the percentage lactose content in colostrum as it is the major osmotic component that determines milk yield (Theil et al., 2014). Lactose synthesis depends on the availability of its main precursor (Shennan and Peaker, 2000). Because of the lack of any relation, diet and endocrine factors are probably more likely to explain (the low) colostral lactose variation than sow, litter and parturition factors.

CONCLUSION

Colostrum yield and colostral fat are affected by different factors at both sow and litter level. Colostrum yield is found to be significantly affected by t_{FS}, gestation length and the interaction between gestation length and LW_{SP}. This study clearly demonstrated that t_{FS} is a major factor involved in colostrum yield. Further research is needed to elucidate the observed significant influence of gestation length (per se) and (combined with the effect of the) LW_{SP} on colostrum yield by the sow. Colostral fat was significantly affected by sow breed, parity and the number of live-born piglets. This study confirmed the potential of selection strategies to improve colostral fat. Furthermore each unit decrease in parity or each unit increase in number live-born piglets is related with a higher colostral fat percentage. Management in the farrowing house might be adjusted for these observations to optimize colostrum yield, composition and intake in order to maximize (re)production potential of sows and piglets.

LITERATURE CITED

- Baxter, E.M., S. Jarvis, R.B. D'Eath, D.W. Ross, S.K. Robson, M. Farish, I.M. Nevvison, A.B. Lawrence, and S.A. Edwards. 2008. Investigating the behavioural and physiological indicators of neonatal survival in pigs. Theriogenology 69: 773-783.
- Boyd, R.D. and R.S. Kensinger. 1998. Metabolic precursors for milk synthesis. In: The lactating sow. M. W. A. Verstegen, P.J. Moughan and J.W. Schrama. Wageningen Pers, Wageningen, The Netherlands, p 71-95.
- Decaluwé, R., D. Maes, I. Declerck, A. Cools, B. Wuyts, S. De Smet and G.P.J. Janssens. 2013. Changes in back fat thickness during late gestation predict colostrum yield in sows. Animal 7: 1999-2007.
- Decaluwé, R., D. Maes, B. Wuyts, A. Cools, S. Piepers, and G.P.J. Janssens. 2014. Piglets' colostrum intake associates with daily weight gain and survival until weaning. Livest Sci 162: 185-192.
- Devillers, N. 2004. Variabilité de la production de colostrum chez la truie: origine et conséquences pour la survie du porcelet. PhD Thésis. Université de Rennes, France.
- Devillers N., C. Farmer, J. Le Dividich, and A. Prunier. 2007. Variability of colostrum yield and colostrum intake in pigs. Animal 1: 1033-1041.
- Devillers N., J. Le Dividich, C. Farmer, A.M. Mounier, M. Lefebvre, and A. Prunier. 2005. Origine et conséquences de la variabilité de la production par la truie et de la consommation de colostrum par les porcelets. J. Rech. Porcine 37: 435-442.
- Devillers N., J. Le Dividich, and A. Prunier. 2011. Influence of colostrum intake on piglet survival and immunity. Animal 5: 1605-1612.
- Devillers, N., J. van Milgen, A. Prunier, and J. Le Dividich. 2004. Estimation of colostrum intake in the neonatal pig. Anim. Sci.78: 305-313.
- Dohoo, I., W. Martin and H. Stryhn. 2009. Veterinary Epidemiological Research. 2nd ed., Ver Inc, Charlottetown, Prince Edwards Island, Canada, p.330.
- Edwards, S.A. 2002. Perinatal mortality in the pig: environmental or physiological solutions? Livest. Prod. Sci. 78: 3-12.
- Fahmy, M.H. 1972. Comparative study of colostrum and milk composition of seven breeds of swine. Can. J. Anim. Sci. 52: 621-627.
- Farmer, C., N. Devillers, J.A. Rooke, and J. Le Dividich. 2006. Colostrum production in swine: from the mmammary glands to the piglets. CAB Rev. 1: 1-16.

- Farmer, C., P. Charagu, and M.F. Palin. 2007. Influence of genotype on metabolic variables, colostrum and milk composition of primiparous sows. Can. J. Anim. Sci. 87: 511-515.
- Farmer, C. and H. Quesnel, 2009. Nutritional, hormonal and environmental effects on colostrum in sows. J. Anim. Sci. 87: 56-64.
- Foisnet, A., C. Farmer, C. David, and H. Quesnel. 2010. Relationships between colostrum production by primiparous sows and sow physiology around parturition. J. Anim. Sci. 88: 1672-1683.
- Foisnet, A., C. Farmer, C. David, and H. Quesnel. 2011. Farrowing induction induces transient alterations in prolactin concentrations and colostrum composition in primiparous sows. J. Anim. Sci. 89: 3048-3059.
- Fraser, D. 1984. Some factors influencing the availability of colostrum to piglets. Anim. Prod. 39: 115-123.
- Guy, M.A., T.B. McFadden, D.C. Cockrell and T.E. Besser. 1994. Regulation of colostrum formation in beef and dairy cows. J. Dairy Sci. 77: 3002-3007.
- Herpin, P., J. Le Dividich, and M. van Os. 1992. Contribution of colostral fat to thermogenesis and glucose homeostasis in the newborn pig. J. Dev. Physiol. 17: 133-141.
- Herpin P., I. Louveau I., M. Damon, and J. Le Dividich. 2005. Environmental and hormonal regulation of energy metabolism in early development of the pig. In: Burrin D.G., and Mersmann H., editors, Biology of metabolism in growing animals. Elsevier, New York p. 345-374.
- Jackson, J.R., W.L. Hurley, R.A. Easter, A.H. Jensen, and J. Odle. 1995. Effects of induced or delayed parturition and supplemental dietary fat on colostrum and milk composition. J. Anim. Sci. 73: 1906-1913.
- Klobasa, F., and J.E. Butler. 1987. Absolutive and relative concentrations of immunoglobulins G, M, and A, and albumin in the lacteal secretion of sows of different lactation number. Am. J. Vet. Res. 48: 176-182.
- Klobasa, F., E. Werhahn E., and J.E. Butler. 1987. Composition of sow milk during lactation. J. Anim. Sci. 64: 1458-1466.
- Le Dividich, J., P. Herpin, and R.M. Rosario-Ludovino. 1994. Utilization of colostral energy by the newborn pig. J. Anim. Sci. 72: 2082-2089.
- Le Dividich J., J.A. Rooke, and P. Herpin. 2005. Nutritional and immunological importance of colostrum for the new-born pig. J. Agric. Sci. 143: 469-485.

- Maes, D.G.D., G.P.J. Janssens, P. Delputte, A. Lammertyn, and A. de Kruif. 2004. Back fat measurements in sows from three commercial pig herds: relationship with reproductive efficiency and correlation with visual body condition scores. Livest. Prod. Sci. 91:57-67.
- Mellor, D.J., and F. Cockburn. 1986. A comparison of energy metabolism in the newborn infant, piglet and lamb. Q. J. Exp. Physiol. 71: 361-371.
- Mota-Rojas, D., J. Martinez-Burnes, D. Villanue-Garcia, P. Roldan-Santiago, M.E. Trujillo-Ortega, H. Orozco-Gregorio, H. Bonilla-Jaime, and A. Lopez-Mayagoitia. 2012. Animal welfare in the newborn piglet: a review. Vet Med 57: 338-349.
- Passillé, A. M. de, and J. Rushen. 1989. Using early suckling behavior and weight gain to identify piglets at risk. Can. J. Anim. Sci. 69: 535-544.
- Quesnel, H. 2011. Colostrum production by sows: variability of colostrum yield and immunoglobulin G concentrations. Animal 5: 1546-1553.
- Quesnel, H., C. Farmer, and N. Devillers. 2012. Colostrum intake: influence on piglet performance and factors of variation. Livest. Sci. 146: 105-114.
- Rooke, J.A., and I.M. Bland. 2002. The acquisition of passive immunity in the newborn piglet. Livest. Prod. Sci. 78: 13-23.
- Senger, P.L. 2005. Pathways to pregnancy and parturition. 2nd ed., Cadmus Professional Communications, Science Press Division, Ephrata, USA, p.102-344.
- Shennan, D.B., and M. Peaker. 2000. Transport of milk constituents by the mammary gland. Phys. Reviews 80: 925-951.
- Theil, P.K., C. Lauridsen, and H. Quesnel. 2014. Neonatal piglet survival: Impact of sow nutrition around parturition on fetal glycogen deposition and production and composition of colostrum and transient milk. Animal 8: 1021-1030.
- Theil, P.K., M.O. Nielsen, M.T. Sorensen, and C. Lauridsen. 2012. Lactation, milk and suckling. In: K. E. Bach Knudsen, N. J. Kjeldsen, H. D. Poulsen and B. B. Jensen, editors, Nutritional physiology of pigs. Danish Pig Research Centre, Copenhagen. p. 1-47.
- Theil, P.K., K. Sejrsen, W.L. Hurley, R. Labouriau, B. Thomsen, and M.T. Sorensen 2006. Role of suckling in regulating cell turnover and onset and maintenance of lactation in individual mammary glands of sows. J. Anim. Sci. 84: 1691-1698.
- Tuchscherer, M., B. Puppe, A. Tuchscherer, and U. Tiemann. 2000. Early identification of neonates at risk: traits of newborn piglets with respect to survival. Theriogenology 54: 371-388.

- Vanderhaeghe, C., J. Dewulf, J. Jourquin, A. de Kruif, and D. Maes. 2011. Incidence and prevention of early parturition in sows. Reprod. Domest. Anim. 46: 428-433.
- Varley, M.A., A. Maitland, and A. Towle. 1986. Artificial rearing of piglets: the administration of two sources of immunoglobulins after birth. Anim. Prod. 43: 121-126.
- Xu, R.J., F. Wang, and S.H. Zhang. 2000. Postnatal adaptation of the gastrointestinal tract in neonatal pigs: a possible role of milk-borne growth factors. Livest. Prod. Sci. 66: 95-107.
- Zou S., D.G. McLaren, and W.L. Hurley 1992. Pig colostrum and milk composition: comparisons between Chinese Meishan and US breeds. Livest. Prod. Sci. 30: 115-127.

Chapter 5

Sow and piglet factors determining variation of colostrum intake between and within litters

I. Declerck, S. Sarrazin, J. Dewulf and D. Maes

Animal, accepted.

V. SOW AND PIGLET FACTORS DETERMINING VARIATION OF COLOSTRUM INTAKE BETWEEN AND WITHIN LITTERS

ABSTRACT

Colostrum intake has a short and long-term beneficial impact on piglet performance and mortality. Sows' colostrum production and piglets' colostrum intake (**CI**) are limited and highly variable. The present study investigated sow and piglet factors explaining the variation of CI between and within litters. The coefficient of variation for CI and birth weight ($\mathbf{BW_b}$) of all piglets within a litter was calculated to evaluate the variation of CI and BW_b within a litter (colostrum and litter BW_b heterogeneity, respectively). A total of 1 937 live-born piglets from 135 litters from 10 commercial herds were included. Colostrum intake per piglet averaged 371 ± 144 g and was affected by breed ($P = 0.02$). It was lower when oxytocin was administered to the sow during parturition ($P = 0.001$) and with increased litter size ($P < 0.001$). It was higher when the interval between birth and first suckling decreased ($\mathbf{t_{FS}}$, $P < 0.001$). Colostrum intake was positively influenced by BW_b ($P < 0.001$) and this association was more pronounced in piglets from Topigs ($P = 0.03$) and Hypor ($P = 0.03$) sows compared to piglets from Danbred sow breeds. The positive relationship between CI and BW_b was more pronounced when t_{FS} lasted longer ($P = 0.009$). Heterogeneity in colostrum intake averaged 31 ± 11%, it increased when oxytocin was applied during farrowing ($P = 0.004$) and when stillbirth occurred ($P = 0.006$). Colostrum heterogeneity was positively associated with litter size ($P < 0.001$) and litter BW_b heterogeneity ($P = 0.01$). The positive relationship between colostrum and litter BW_b heterogeneity was more pronounced when oxytocin was applied during farrowing ($P = 0.04$). The present study demonstrated that oxytocin should be used cautiously in sows during farrowing. Farrowing and colostrum management should prevent or counteract the adverse influences of stillbirth, large and heterogeneous litters on colostrum intake and colostrum heterogeneity. The study also confirmed the expected association between BW_b and CI and indicated that the impact of BW_b on CI was different among breeds (Hypor versus Danbred) and dependent on piglets' latency to first suckling. Hence, colostrum management should focus on low birth weight piglets, especially in some breeds, and low CI in low birth weight piglets can be counteracted by shortening the t_{FS}.

Key words: colostrum, heterogeneity, intake, piglets, variation

IMPLICATIONS

Piglets' colostrum intake is crucial regarding short and long-term survival and performance. However, sows' colostrum production is limited and piglets' colostrum intake is highly variable between and within litters. Therefore, knowledge about factors determining colostrum intake variation within and between litters will enable pig producers to optimize colostrum management and ultimately, maximize piglets' lifetime production potential.

INTRODUCTION

The crucial role of colostrum on piglet pre-weaning mortality and performance has been reported by several studies (e.g. Devillers et al., 2007; Decaluwé et al., 2014b). A longer-term impact on mortality and performance was suggested (Devillers et al., 2011; Quesnel et al., 2012) and has been recently demonstrated (Declerck et al., 2016b). Hence, colostrum management is a promising tool to limit economic losses, health and welfare concerns in commercial pig herds. The supply of energy (Herpin et al., 2005; Le Dividich et al., 2005), immunity (Rooke and Bland, 2002) and bio-active compounds (Xu et al., 2000) by colostrum may explain its positive short and long-term effects. Total colostrum yield is reported to be independent from litter size (e.g. Devillers et al., 2007; Foisnet et al., 2010), compromising the individual piglet intake of sufficient colostrum in large litters of high-prolific sows. Moreover, piglets' colostrum intake is not only limited and highly variable across piglets between litters (Farmer and Quesnel, 2009), but also within litters (Le Dividich et al., 2005; Devillers et al., 2011). By understanding this variation, farrowing management can be adjusted to optimize the use of available colostrum between and within litters. Studies regarding colostrum intake in high-prolific commercial swine herds are needed to unravel the factors explaining the variation in piglets' colostrum intake. As colostrum intake depends on both the sow's ability to produce colostrum and the piglets' ability to extract, suckle and ingest the colostrum (Devillers et al., 2011), the present study aimed to unravel which sow and piglet factors determine the variation of colostrum intake between and within litters at commercial pig herds.

MATERIALS AND METHODS

Study population and animal handling

In total, 135 litters comprising 1 937 live-born piglets from 10 different commercial pig herds in Belgium were enrolled in the study. A detailed description of the study population can be found in Declerck et al. (2016a and 2016b). Studies were approved by the Ethical Committee of the Faculty of Veterinary Medicine, Ghent University, Belgium (no. 2013/98 and no. 2011/85). The herds were selected based on willingness of the farmer to cooperate. Five different sow breeding lines were included: one of own crossbred Landrace and four commercial crossbred sows (PIC, Topigs, Hypor and Danbred). In each farm, only one sow breeding line was present. All sows were inseminated with semen from Piétrain boars. Table 1 represents the main herd characteristics, the number of studied sows per herd and the outcome and predictor variables per herd. Farrowing induction was not applied during the study period. Continuous farrowing supervision 24 h a day was performed and sows starting parturition during supervision were enrolled in the study. No restriction on parity or on gestation length was imposed. However, it was taken into account that parity and gestation length were randomly distributed across the different herds and breeds. The periparturient management routines of the herds were maintained as much as possible. The administration of oxytocin or manual birth assistance performed by the farrowing staff was registered. Immediately after birth, piglets were dried with a paper towel and weighed. The birth order was marked on their back and piglets were individual ear tagged and placed back on the place from where they were taken. Furthermore, time of birth and time of first suckling (teat in mouth) were registered. Piglets were weighed individually 24 h after birth of the first littermate. Cross-fostering was not allowed before the second day of life.

.

Table 1 *Herd characteristics, the number of studied sows per herd and the herd averages regarding the outcome and predictor variables from 1,582 piglets originating from 135 litters on ten commercial pig herds*

	Herd number									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Breed of sows	Crossbred Landrace	PIC	Topigs	Topigs	Topigs	Hypor	PIC	Danbred	Danbred	Hypor
Number of sows	300	1700	450	520	450	600	700	750	300	600
Batch-production-system, weeks	3	2	5	5	4	4	3	2	4	4
Lactation period, weeks	4	3	3	3	3	3	4	3	3	3
Piglets weaned/sow/year	25	27	30	25	26	27	26	28	30	27
Number of studied sows	10	35	10	10	10	20	10	10	10	10
Colostrum intake, g	380	367	389	353	345	426	387	290	324	432
Colostrum heterogeneity[1], %	33	33	30	24	36	30	33	31	34	30
Sow factors										
Parity	3.8	3.9	3.2	2.7	4.5	4.7	3.9	3.9	3.5	3.6
1	3	2	0	3	1	2	1	1	1	2
2-4	4	20	9	5	6	9	5	6	8	4
5-11	3	13	1	2	3	9	4	3	1	4
Gestation length, days	114.5	114.0	113.7	114.1	114.3	115.5	115.0	114.9	115.5	114.3
111-113	0	14	3	0	0	2	0	1	0	0
114-115	10	15	7	10	10	6	9	9	4	10

116	0	6	0	0	0	12	1	0	6	0
Parturition duration, min	204	205	258	203	243	193	226	172	349	213
Presence of stillbirths, n	4	24	5	5	8	19	4	3	6	5
Use of oxytocin, n	3	5	3	3	8	15	2	4	5	1
Manual palpation, n	4	9	2	1	0	3	3	1	2	2
Litter size, n	13.3	14.5	15.8	14.8	14.9	14.1	12.7	17.1	18.1	14.9
Litter heterogeneity[2], %	20.0	23.8	20.9	17.4	17.6	20.9	22.5	20.4	18.2	19.4
Piglet factors										
t_{FS},3 min	39	37	35	52	41	51	56	62	79	48
Birth weight, kg	1.37	1.17	1.20	1.17	1.23	1.33	1.30	1.19	.26	1.39
Birth rank										
Birth interval	20	15	17	16	15	15	20	10	21	13
Gender, %										
Male	54	48	50	44	46	55	47	46	50	55
Female	46	52	50	56	54	45	53	54	50	45

[1, 2] *Colostrum and litter heterogeneity = the coefficient of variation for colostrum intake and birth weight of all piglets within a litter, respectively, %.*

[3] t_{FS} *= the interval between birth and first suckling, min.*

Colostrum intake

Colostrum intake was estimated using the model described by Theil et al. (2014). This mechanistic model quantifies colostrum intake by sow-reared piglets with normal suckling pattern and normal physical activity compared to bottle-fed piglets. The model is based on 24-h weight gain (**WG**; g), birth weight ($\mathbf{BW_b}$; kg) and duration of colostrum intake (**D**; min). Colostrum intake was only calculated from 1 582 piglets as colostrum intake from piglets that died during the first 24 h was not calculated. Duration of colostrum intake was defined as the time between the first and the second weighing. The equation is the following: -106+ 2.26 WG + 200 BW_b + 0.111 D – 1,414 WG/D + 0.0182 WG/BW_b. To evaluate the variation of colostrum intake within a litter, the CV (%) for colostrum intake of all piglets within the litter was calculated by dividing the standard deviation of colostrum intake between littermates by the mean colostrum intake of a litter. This CV will further be referred to as colostrum heterogeneity.

Definitions and data handling

The outcome variables (piglets' colostrum intake and colostrum heterogeneity) were analysed as continuous variables. The predictor variables at sow level were breed, parity, gestation length, duration of farrowing, use of oxytocin during parturition, manual birth assistance, stillbirth, litter size and litter BW_b heterogeneity. Sows belonged to five different breeding lines: Crossbred Landrace, PIC, Topigs, Hypor or Danbred. In the present study, parity ranged from one to 11 and was categorized in three groups namely parity one (young sows), parity two to four (intermediate sows), parity five or higher parity (old sows). Gestation was assumed to start at the day of first insemination (day zero) and day of parturition was assumed to be the last day of gestation. Gestation length varied from 111 to 116 days and was categorized in three groups, namely 111 to 113 days (early parturition), 114 to 115 days (normal parturition) and 116 days (late parturition). The duration of farrowing was calculated as the time interval between the birth of the first and last live-born piglet. A stillborn piglet was defined as a piglet without signs of decay and found dead behind the sow. The use of oxytocin, manual birth assistance and the occurrence of stillbirth were considered as binary variables. Litter size was defined as the number of live-born piglets. To evaluate the birth weight variation within a litter, the CV for birth weight of all piglets within the litter was calculated and will be further referred to as litter BW_b heterogeneity. Litter size and litter

BW_b heterogeneity were considered as continuous variables. The predictor variables at piglet level were the interval between birth and first suckling (**t_{FS}**), birth weight, birth rank, birth interval and gender. The interval between birth and first suckling was calculated based on the time of birth and the time of first suckling. All piglet factors were considered as continuous on behalf of the binary variable gender.

Statistical analysis

Basic descriptive statistics were used to explore the outcome variables (piglets' colostrum intake and colostrum heterogeneity) and predictor variables at sow level (breed, parity, gestation length, duration of farrowing, use of oxytocin during parturition, manual birth assistance, stillbirth, litter size and litter BW_b heterogeneity) and predictor variables at piglet level (t_{FS}, birth weight, birth rank, birth interval and gender). Colostrum intake, colostrum heterogeneity, farrowing duration, litter size, litter heterogeneity and birth weight were normally distributed, whereas parity, gestation length, t_{FS} and birth interval were not normally distributed. Results are reported as mean ± SD or median [IQR] when variables are normally or not normally distributed, respectively.

To model possible associations between the outcome and predictor variables, two linear mixed models were fitted. A random herd effect was included to correct for clustering of sows in a herd and to correct for confounding factors at herd level. Similarly, a nested random sow effect was included to correct for clustering of piglets within litters and to correct for confounding factors at the sow level. Initially, univariable linear mixed regression models between the outcome variables and each predictor variable were examined. Statistical significance in this step was assessed at $P < 0.20$. Furthermore, for continuous predictor variables, the assumption of linearity was examined by the Loess curves between each individual predictor variable and the outcome variables and by the scaled residuals of the univariable models. If necessary, transformation of the predictor variables or inclusion of higher order effects was considered. Regarding t_{FS} and birth interval, a log transformation was performed to obtain a linear association with the outcome variables. Secondly, Pearson or Spearman rank correlation coefficients, for either normally or not normally distributed independent variables, respectively, were calculated among the significant independent variables to avoid multicollinearity in the next steps. None correlation between two selected independent variables was higher than 0.60 and therefore, multicollinearity could be never assumed. Then, the independent variables were used to build a multivariable linear regression

model by a manual stepwise backward model building procedure. Statistical significance in this step was assessed at $P < 0.05$. The estimates of the significant predictor variables are presented with their corresponding 95% confidence interval. Finally, all 2-way interactions were tested and removed when non-significant ($P > 0.05$). To check whether the assumptions of normality and homogeneity of variance had been fulfilled normal probability plots of residuals and plots of residuals versus predicted values were generated. Influence of outliers was tested through Cook's distance, DFFITS (the change in the predicted value for a point, obtained when that point is left out of the regression), and DFBETAS (the standardized difference in the parameter estimate due to deleting the observation). No influential cases were found. Statistical analysis was performed in SAS 9.4 (SAS Institute Inc., Cary, USA).

RESULTS

Descriptive results

Factors at sow and piglet level determining the variation of colostrum intake of 1 582 piglets were investigated. Colostrum intake per piglet averaged 371 ± 144 g. Colostrum heterogeneity averaged 31 ± 11%. Sows had a median parity of 3 [2; 5] and a median gestation length of 115 [114; 116] days. Farrowing lasted on average 221 ± 99 min. Oxytocin was administered to 49 (36%) sows and manual birth assistance was offered to 27 (20%) sows. Stillbirth occurred in 74 (55%) litters. Litter size averaged 14 ± 3 live-born piglets. Litter heterogeneity was 20 ± 6%. The median interval between birth and first suckling lasted 37 [20; 67] min. Piglets' birth weight averaged 1.28 ± 0.32 kg. The median birth interval was 9 [3; 18] min. The number of male live-born piglets was 952 (49%). At the herd level, descriptive data of the outcome and predictor variables are summarized in Table 1.

Colostrum intake

Parity, gestation length, manual birth assistance, stillbirth and birth rank did not affect piglets' colostrum intake regarding univariable analysis ($P > 0.20$). Breed, the use of oxytocin during farrowing, litter size, birth weight and t_{FS} were retained in the final multivariable model. No multicollinearity was assumed between the remaining variables. In the final multivariable mixed model (Table 2), two significant interaction terms (birth weight x breed and birth weight x t_{FS}) were included. In order to interpret the interacted parameters (birth weight, breed and t_{FS}) in a more comprehensive way, the variable birth weight was centered by subtracting

the mean birth weight (1.28 kg). Hence, interaction terms become zero when the model considered piglets with the mean birth weight. The intercept represents a Danbred piglet with a mean birth weight which dam was not injected with oxytocin during farrowing. The intercept is associated with a mean colostrum intake of 570 g (95% CI 472 to 667).

Table 2 *Parameter estimates of the multivariable linear mixed model with colostrum intake (g) as the outcome variable*

Predictor variable	Estimate	F-value (df)	P-value
Breed		3.03 (4, 1380)	0.017
Own Crossbred Landrace	-14		0.57
PIC	22		0.28
Topigs	26		0.15
Hypor	50		0.007
Danbred	Ref.		
Use of oxytocin during farrowing			
Yes	-37	10.83 (1, 1380)	0.001
No	Ref.		
Litter size, n	-9	24.42 (1, 1380)	< 0.001
Log t_{FS}[1], min	-15	17.80 (1, 1380)	< 0.001
Birth weight, kg (centered)	152	19.83 (1, 1380)	< 0.001
Birth weight (centered) x breed		17.80 (1, 1380)	< 0.001
Own Crossbred Landrace	-15		0.68
PIC	-14		0.64
Topigs	63		0.03
Hypor	59		0.03
Danbred	Ref.		
Birth weight (centered) x log t_{FS}	26	6.90 (1, 1380)	0.009

[1] *t_{FS} = the interval between birth and first suckling, min.*

Colostrum intake per piglet varied significantly with breed (P = 0.02). Considering piglets with an average birth weight (1.28 kg), Hypor piglets consumed 50 g (95% CI 14 to 87) more colostrum compared to Danbred piglets (P = 0.007). Colostrum intake per piglet decreased on average 37 g (95% CI 15 to 59) when oxytocin was applied to the dam (P = 0.001). Colostrum intake was negatively associated with litter size as piglets' colostrum intake decreased on average 9 g (95% CI 6 to 13) for each additional live-born piglet (P < 0.001). A positive association between colostrum intake and birth weight was observed (P < 0.001), e.g. colostrum intake by Danbred piglets with a t_{FS} of 1 min increased on average 152 g (95% CI 62 to 242) with each increase of one kg in birth weight. Furthermore, the strength of this positive association between colostrum intake and birth weight varied across breeds (Figure 1). Regarding piglets with a t_{FS} of 1 min, a higher birth weight of one additional kg resulted in a significantly steeper increase of colostrum intake in Topigs (215 g, 95% CI 134 to 297) compared to Danbred piglets (152 g, 95% 62 to 242) (P = 0.03) and in Hypor (211 g, 95% CI 132 to 290) compared to Danbred piglets (152 g, 95% 62 to 242) (P = 0.03).

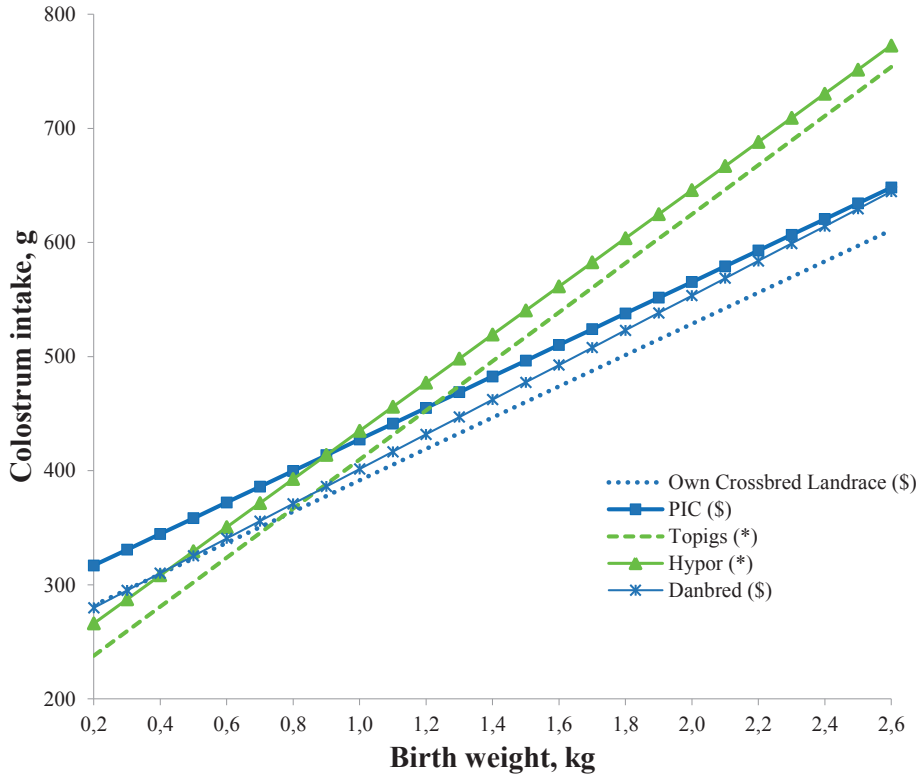

Figure 1. *To illustrate the interaction between birth weight and breed on colostrum intake, hypothetical groups of piglets of different breeds with birth weights varying between the minimum (0.2 kg) and maximum (2.6 kg) observed birth weight, with an interval between birth and first suckling of one minute and originating from litters with 14 live-born piglets which dam was not injected with oxytocin were generated. For all breeds, a positive association between colostrum intake and birth weight was observed. However, this association was more pronounced (steeper slope) for Topigs and Hypor piglets (symbol '*') compared to the other breeds (symbol '$').*

A positive association between colostrum intake and t_{FS} was observed. Considering piglets weighing the mean birth weight (1.28 kg), piglets' colostrum intake decreased on average 15 g (95% CI 8 to 22) with each unit increase of $logt_{FS}$. The strength of this positive association between colostrum intake and birth weight was more pronounced for longer t_{FS} (Figure 2). Regarding Danbred piglets, a higher birth weight of one additional kg resulted in a significantly steeper increase of colostrum intake if t_{FS} lasted longer (P = 0.009).

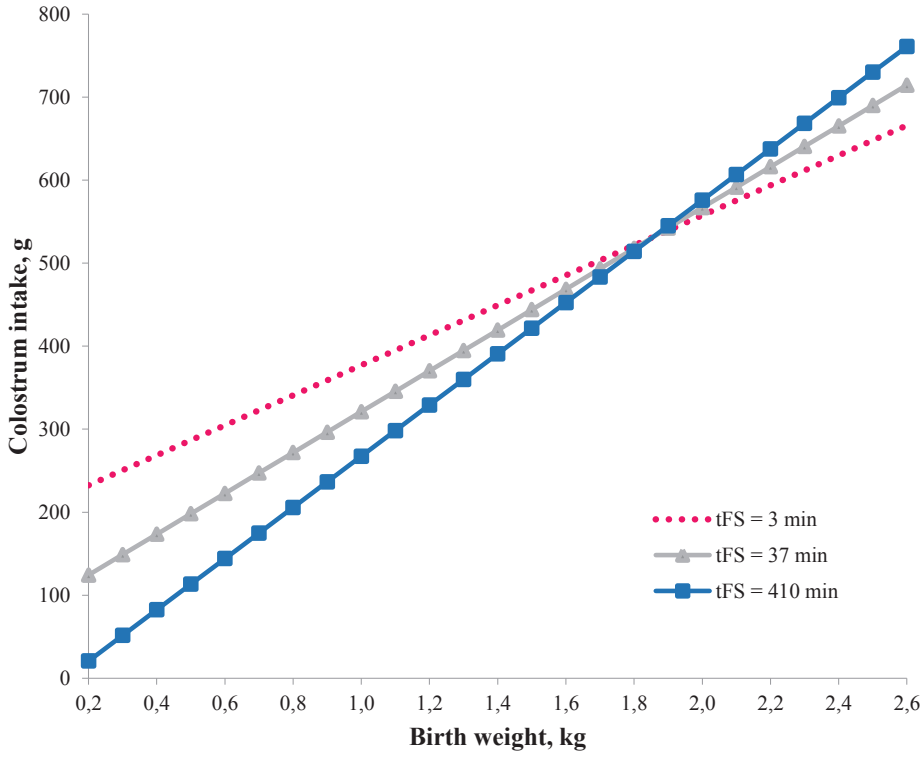

Figure 2. *To illustrate the interaction between birth weight and the interval between birth and first suckling (t_{FS}) on colostrum intake, hypothetical groups of Danbred piglets with birth weights varying between the minimum (0.2 kg) and maximum (2.6 kg) observed birth weight, with t_{FS} lasting 3 min (minimum), 37 min (median) and 410 min (maximum), and originating from litters with 14 live-born piglets which dam was not injected with oxytocin were generated. For all t_{FS}, a positive association between colostrum intake and birth weight was observed. However, this association was more pronounced (steeper slope) for longer t_{FS}.*

Colostrum heterogeneity

Breed and gestation length were excluded by univariable analysis (P > 0.20). Stillbirth, the use of oxytocin during farrowing, litter size, litter BW_b heterogeneity were retained in the final multivariable model. No multicollinearity was assumed between the remaining variables. In the final multivariable mixed model (Table 3), a significant interaction term (the use of oxytocin x litter BW_b heterogeneity) was included. In order to interpret the interacted parameters (the use of oxytocin during parturition and litter heterogeneity) in a more comprehensive way, the variable litter BW_b heterogeneity was centered by subtracting the mean litter BW_b heterogeneity (20%). Hence, the interaction term became zero when the model considered litters with the mean litter BW_b heterogeneity (20%).

Table 3 *Parameter estimates of the multivariable linear mixed model with colostrum heterogeneity[1] (%) as the outcome variable*

Predictor variable	Estimate	F-value (df)	P-value
Use of oxytocin during farrowing			
Yes	5.03	8.63 (1, 119)	0.004
No	Ref.		
Stillbirth			
Yes	4.58	8.01 (1, 119)	0.006
No	Ref.		
Litter size, n	0.99	11.61 (1, 119)	< 0.001
Litter heterogeneity[2], % (centered)	0.40	22.07 (1, 119)	0.01
Use of oxytocin x litter heterogeneity (centered)			
Yes	0.55	4.23 (1, 119)	0.04
No	Ref.		

[1, 2]Colostrum and litter heterogeneity = the CV for colostrum intake and birth weight of all piglets within a litter, respectively, %.

In litters with the mean litter BW_b heterogeneity (20%), the colostrum heterogeneity increased on average 5.03% (95% CI 1.64 to 8.42) when oxytocin was administered to the dam (P = 0.004, Figure 3). In litters with stillbirth, colostrum heterogeneity was 4.58% (95% CI 1.38 to 7.78) higher compared to litters without stillbirth (P = 0.006). For every extra live-born piglet, colostrum heterogeneity increased 0.99% (95% CI 0.42 to 1.57) (P < 0.001). A positive association between colostrum heterogeneity and litter BW_b heterogeneity was observed. Furthermore, the strength of this positive association between colostrum heterogeneity and litter BW_b heterogeneity was more pronounced when oxytocin was applied during farrowing (Figure 3). When oxytocin was not applied during farrowing, colostrum heterogeneity increased 0.40% (95% CI 0.09 to 0.72) with each 1% increase in the litter BW_b heterogeneity (P = 0.01). When oxytocin was applied, colostrum heterogeneity increased 0.95% (95% CI 0.50 to 1.42) with each 1% increase in the litter BW_b heterogeneity (P = 0.04).

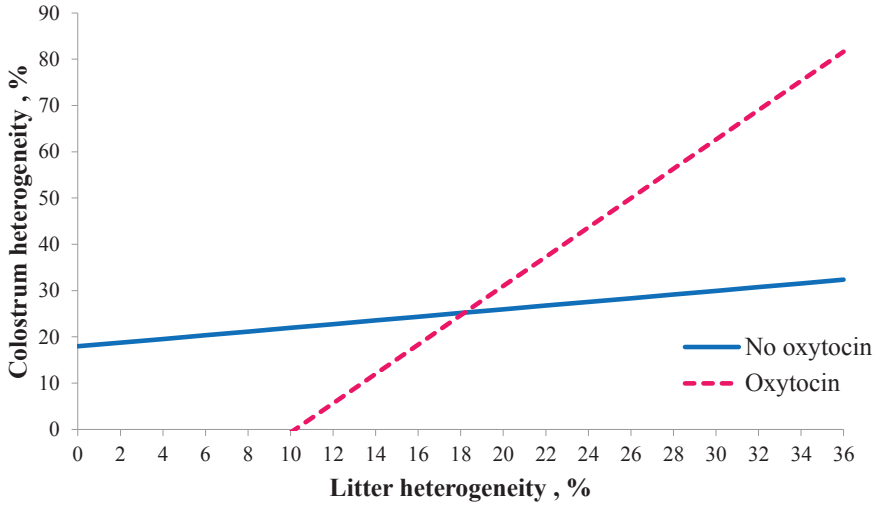

Figure 3. *To illustrate the interaction between the use of oxytocin and litter heterogeneity on colostrum heterogeneity, hypothetical litters with 14 live-born and no stillborn piglets and with a litter heterogeneity varying between the minimum (0%) and maximum (36%) observed litter heterogeneity were generated. Regardless whether oxytocin was used during farrowing or not, a positive association between colostrum heterogeneity and litter heterogeneity was observed. However, this association was more pronounced (steeper slope) when oxytocin was used.*

DISCUSSION

Most previous studies estimated colostrum intake by the regression equation of Devillers et al. (2004) (Devillers et al., 2007; Quesnel, 2011; Decaluwé et al., 2014b), whereas colostrum intake in this study was estimated by the mechanistic model of Theil et al. (2014). As Devillers' equation was obtained from bottle-fed piglets, colostrum intake of sow-reared piglets is underestimated (mainly) due to the lower amount of energy needed to obtain colostrum in bottle-fed versus sow-reared piglets. The equation by Theil et al. (2014) is believed to quantify the colostrum intake of sow-reared piglets more accurately and therefore better suited for this study with sow-reared piglets. As the study was conducted across different commercial herds, the present results have a high external validity and practical relevance.

Breed

In the present study, piglets' colostrum intake was affected by breed. To our knowledge, previous studies did not observe any relationship between colostrum intake and breed, as most of them included only one breed (e.g. Devillers et al., 2007; Decaluwé et al., 2014a;b). Several hypotheses could explain this association. First, colostrum production and hence, colostrum intake might be different among breeds. However, in previous work, we showed that colostrum yield did not differ significantly between breeds (Declerck et al., 2015). Therefore, the explanation of the association between breed and colostrum intake is more likely related to the significant differences between breeds regarding litter size, birth weight and t_{FS} (data not shown). Also other breed factors, such as udder morphology or teat access (Vasdal and Andersen, 2012; Ocepek at al., 2016) might influence the different colostrum intake between breeds.

Oxytocin

When oxytocin was administered during farrowing to the sow, colostrum intake decreased, colostrum heterogeneity increased and the strength of the positive association between colostrum and litter BW_b heterogeneity was more pronounced. These observations seem to be contradictory regarding the role of oxytocin in milk ejection, postpartum mammary growth and mobilization of body reserves (Kent et al., 2003; Valros et al., 2004). However, some

hypotheses can explain the observed negative impact of oxytocin administration on colostrum intake and colostrum heterogeneity. First, the lower colostrum intake could be due to the underlying indication of oxytocin administration. Oxytocin might be indicated to shorten farrowing duration or speeding up placenta expulsion (Alonso-Spilsbury et al., 2004; Peltoniemi et al., 2016). The hormones involved in the parturition process are also involved in milk production and milk ejection. Hence, hormonal imbalances resulting in prolonged farrowing and leading to the use of oxytocin may be the underlying mechanism of a lower colostrum production resulting in a lower piglets' colostrum intake. Secondly, the lower colostrum intake and the higher colostrum heterogeneity could be related with the consequences of oxytocin (mis)use such as a higher risk of dystocia and intrapartum asphyxia (Alonso-Spilsbury et al., 2004; Mota-Rojas et al., 2005). Intrapartum asphyxia impairs the vitality in piglets and hence, compromises their colostrum intake (Mota-Rojas et al., 2005). The use of oxytocin increased the influence of litter BW_b heterogeneity on colostrum heterogeneity as the risk of asphyxia and impaired vitality by oxytocin (misuse) (Mota-Rojas et al., 2005) might be higher in heterogeneous litters with more low birth weight piglets (Milligan et al., 2001) as low birth weights are more susceptible to intrapartum asphyxia compared to normal birth weight littermates (Herpin et al., 1996; Pedersen et al., 2011). Finally, the injection itself and the myometrial contractions induced by oxytocin might also be stressful and harmful to sows and hence, compromise suckling behaviour and milk letdown by the sows. Further research is needed to elucidate how oxytocin should be used regarding colostrum management.

Stillbirth

Colostrum heterogeneity was higher in litters with stillbirth. Quesnel et al. (2012) reported that colostrum yield was negatively associated with the number of stillborn piglets and hence, the lower amount of colostrum in litters with stillbirth could result in more competition among littermates leading to higher colostrum heterogeneity. However, stillbirth was not related with colostrum yield in a previous study (Declerck et al., 2015). The current observation of higher colostrum heterogeneity in litters with stillbirth might be associated with the fact that in litters with stillbirth, the live-born littermates might also be weakened by temporary hypoxia (Herpin et al., 1996).

Litter size

When litter size increased, colostrum intake decreased and colostrum heterogeneity increased. As colostrum production is independent from litter size (e.g. Le Dividich et al., 2005; Foisnet et al., 2010; Quesnel et al., 2012; Declerck et al., 2015), colostrum intake is especially limited in large litters. Large litters are associated with more competition and teat fights (Milligan et al., 2001) and hence, colostrum ejection might be disturbed (Andersen et al., 2011). Moreover, in large litters, litter heterogeneity is increased by the higher proportion of low birth weight piglets (Milligan et al., 2001; Quiniou et al., 2002), implying a higher colostrum heterogeneity with increased litter size. In large litters, it is of utmost importance to use the available amount of colostrum optimally among littermates by proper management practices (Vasdal et al., 2011; Muns et al., 2015; 2016).

Litter BW_b heterogeneity

In the present study, colostrum intake by small piglets was negatively correlated with litter heterogeneity (data not shown). Therefore, the observed positive relationship between colostrum and litter BW_b heterogeneity can be linked to the fact that low birth weight piglets are disadvantaged in heterogeneous litters.

Birth weight

Based on the equation to estimate colostrum intake, birth weight largely determines colostrum intake. However, the multivariable model revealed a higher impact of birth weight on colostrum intake than calculated from the equation itself, which is in agreement with the findings of Devillers et al. (2007). The observed positive association between birth weight and colostrum intake is in accordance with previous studies (Tuscherer et al., 2000; Le Dividich et al., 2005; Devillers et al., 2007). It might be linked to a higher vitality, competitive advantage at the udder and a higher ability to suckle colostrum from teats (Devillers et al., 2007; Le Dividich et al., 2005) in heavier versus lighter piglets. Colostrum management should focus on low birth weight piglets, especially in Topigs and Hypor sows due to the interaction between birth weight and breed on colostrum intake.

The interval between birth and first suckling

The present study observed a higher colostrum intake in piglets with short latency to first suckling, which agrees with the role of t_{FS} as a vitality parameter in newborn piglets (Tuchscherer et al, 2000; Baxter et al., 2008). Vitality immediately after delivery is the first factor influencing the acquisition of colostrum by piglets (Devillers et al., 2007; Quesnel et al., 2012). Piglets suckling colostrum fast versus slow after delivery were reported to have higher weaning weights and pre-weaning survival rates (Quesnel et al., 2012; Decaluwé et al., 2014b; Declerck et al., 2016b). The observed negative association between colostrum intake and t_{FS} agrees with the observation that measures helping piglets get to the udder are beneficial for survival (Vasdal et al., 2011). The interaction between t_{FS} and birth weight on colostrum intake confirms that both are important vitality parameters (Devillers et al., 2007; Baxter et al., 2008; Foisnet et al., 2010) and may compensate each other. Hence, facilitating the smallest piglets to access the udder might be promising to optimize colostrum intake in low birth weight piglets.

CONCLUSION

Colostrum intake and heterogeneity are affected by different factors at sow and piglet level. Oxytocin during delivery should be used cautiously as it was negatively related with colostrum intake and increased the heterogeneity in colostrum intake. Furthermore, management measures are needed to prevent or counteract the adverse influences of stillbirth (e.g. parturition supervision), large and heterogeneous litters (e.g. split-suckling) on colostrum intake and heterogeneity. Colostrum management should focus on low birth weight piglets. The positive association between birth weight and colostrum intake was different among breeds and hence, especially in Topigs and Hypor breeds, efforts should be made to increase birth weight and to favor colostrum intake of low birth weight piglets. Farmers can anticipate the adverse influence of low birth weight on colostrum intake by shortening t_{FS} (e.g. drying and placing the piglets at the udder). Colostrum management should be tailored to specific farm observations in order to optimize colostrum intake across piglets between and within litters and ultimately, to maximize piglets' lifetime production.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge all helping colleagues and all pig producers that voluntary agreed to participate in this field study.

LITERATURE CITED

- Alonso-Spilsbury M., D. Mota-Rojas, J. Martinez-Burnes, E. Arch, A. Lopez, R. Ramirez-Necoechea, A. Olmos, M.E. Trujillo. 2004. Use of oxytocin in penned sows and its effect on fetal intra-partum asphyxia. Animal reproduction science 84:157-167.
- Andersen, I.L., E. Naevdal, and K.E. Bøe. 2011. Maternal investment, sibling competition, and offspring survival with increasing litter size and parity in pigs. Behav. Ecol. Sociobiol. 65:1159-1167.
- Baxter, E.M., S. Jarvis, R.B. D'Eath, D.W. Ross, S.K. Robson, M. Farish, I.M. Nevvison, A.B. Lawrence, and S.A. Edwards. 2008. Investigating the behavioural and physiological indicators of neonatal survival in pigs. Theriogenology 69:773-783.
- Decaluwé R., G.P.J. Janssens, M. Englebienne, and D. Maes. 2014a. Effectiveness of different farrowing induction protocols in sows using alphaprostol on day 114 of gestation. Veterinary Record 174:381-386.
- Decaluwé, R., D. Maes, B. Wuyts, A. Cools, S. Piepers, and G.P.J. Janssens. 2014b. Piglets' colostrum intake associates with daily weight gain and survival until weaning. Livest Sci 162:185-192.
- Declerck, I., J. Dewulf, S. Piepers, R. Decaluwé, and D. Maes. 2015. Sow and litter factors influencing colostrum yield and nutritional composition. J. Anim. Sci. 93:1309-1317.
- Declerck I., J. Dewulf, S. Sarrazin, and D. Maes. 2016. Long-term effects of colostrum intake in piglet mortality and performance. J. Anim. Sci. 94:1-11.
- Devillers N., C. Farmer, J. Le Dividich, and A. Prunier. 2007. Variability of colostrum yield and colostrum intake in pigs. Animal 1: 1033-1041.
- Devillers N., J. Le Dividich, and A. Prunier. 2011. Influence of colostrum intake on piglet survival and immunity. Animal 5:1605-1612.
- Devillers, N., J. van Milgen, A. Prunier, and J. Le Dividich. 2004. Estimation of colostrum intake in the neonatal pig. Anim. Sci.78:305-313.
- Farmer, C. and H. Quesnel, 2009. Nutritional, hormonal and environmental effects on colostrum in sows. J. Anim. Sci. 87:56-64.
- Foisnet, A., C. Farmer, C. David, and H. Quesnel. 2010. Relationships between colostrum production by primiparous sows and sow physiology around parturition. J. Anim. Sci. 88:1672-1683.

- Herpin, P., J. Le Dividich, J.C. Hulin, M. Fillaut, F. De Marco, and R. Bertin. 1996. Effects of the level of asphyxia during delivery on viability at birth and early postnatal vitality of newborn pigs. J. Anim. Sci 74:2067-2075.
- Kent J.C., L.M. Kennaugh, and P.E. Hartmann. 2003. Intramammary pressure in the lactating sow in response to oxytocin and during natural milk ejections throughout lactation. Journal of dairy research 70:131-138.
- Le Dividich J., J.A. Rooke, and P. Herpin. 2005. Nutritional and immunological importance of colostrum for the new-born pig. J. Agric. Sci. 143:469-485.
- Milligan, B.N., D. Fraser, and D.L. Kramer. 2001. Birth weight variation in the domestic pig: effects on offspring survival, weight gain and suckling behavior. Applied Animal Behaviour Science 73:179-191.
- Mota-Rojas D., J. Martinez-Burnes, M.E. Trujillo, A. Lopez, A.M.Rosales, R. Ramirez, H. Orozco, A. Merino, M. Alonso-Spilsbury. 2005. Uterine and fetal asphyxia monitoring in parturient sows treated with oxytocin. Anim. Reprod. Sci.86: 131-141.
- Muns, R., X. Manteca, and J. Gasa. 2015. Effects of different management techniques to enhance colostrum intake on piglets' growth and mortality. Animal Welfare. 24:185-192.
- Muns, R., M. Nuntapaitoon, and P. Tummaruk. 2016. Non-infectious causes of pre-weaning mortality in piglets. Livest Sci 184: 46-57.
- Ocepek, M., I. Andersen-Ranberg, SA. Edwards, and IL. Andersen. 2016. Udder characteristics of importance for teat use in purebred and crossbred pigs. J. Anim.. Sci. 94: 780-788.
- Pedersen L.J., P. Berg, G. Jørgensen, and I.L. Andersen. 2011. Neonatal piglet traits of importance for survival in crates and indoor pens. J. Anim. Sci 89:1207-1218.
- Peltoniemi O., S. Björkman, C. Oliviero, and N. Soede. 2016. Positive effect of oxytocin on placenta expulsion. Proceedings 24th International Pig Veterinary Society Congress, 116.
- Quesnel, H. 2011. Colostrum production by sows: variability of colostrum yield and immunoglobulin G concentrations. Animal 5:1546-1553.
- Quesnel, H., C. Farmer, and N. Devillers. 2012. Colostrum intake: influence on piglet performance and factors of variation. Livest Sci 146:105-114.
- Quiniou, N., J. Dagorn, and D. Gaudré. 2002. Variation of piglets' birth weight and consequences on subsequent performance. Livest. Prod. Sci. 78:63-70.

- Rooke, J.A., and I.M. Bland. 2002. The acquisition of passive immunity in the newborn piglet. Livest. Prod. Sci. 78:13-23.
- Theil, P.K., C. Flummer, W.L. Hurley, N.B. Kristensen, R.L. Labouriau, and M.T. Sorensen. 2014. Mechanistic model to predict colostrum intake based on deuterium oxide dilution technique data and impact of gestation and prefarrowing diets on piglet intake and sow yield of colostrum. J. Anim. Sci 92:5507-5519.
- Tuchscherer, M., B. Puppe, A. Tuchscherer, and U. Tiemann. 2000. Early identification of neonates at risk: traits of newborn piglets with respect to survival. Theriogenology 54:371-388.
- Valros A., M. Rundgren, M. Spinka, H. Saloniemi, F. Hulten, K. Uvnäs-Moberg, M. Tomanek, P. Krejci, and B. Algers. 2004. Oxytocin, prolactin and somatostatin in lactating sows: associations with mobilisations of body resources and maternal behaviour. Livest. Prod. Sci. 85:3-13.
- Vasdal, G., I. Østensen, M. Melišová, and, B. Bozděchová. 2011. Management routines at the time of farrowing-effects on teat success and postnatal piglet mortality from loose housed sows. Livestock Science 136:225-231.
- Vasdal, G., I.L. Larsen. 2012. A note on teat accessibility and sow parity – consequences for newborn piglets. Livest Sci 146: 91-94.
- Xu, R.J., F. Wang, S.H. Zhang. 2000. Postnatal adaptation of the gastrointestinal tract in neonatal pigs: a possible role of milk-borne growth factors. Livest. Prod. Sci. 66:95-107.

Chapter 6

Effects of energy supplementation to neonatal (very) low birth weight piglets on mortality, weaning weight, daily weight gain and colostrum intake

I. Declerck, J. Dewulf, R. Decaluwé, and D. Maes

Livestock Science (2016) 183: 48-53.

VI. EFFECTS OF ENERGY SUPPLEMENTATION TO NEONATAL (VERY) LOW BIRTH WEIGHT PIGLETS ON MORTALITY, WEANING WEIGHT, DAILY WEIGHT GAIN AND COLOSTRUM INTAKE

ABSTRACT

Preweaning piglet mortality is an important economic and welfare problem in the commercial pig industry. Energy deficit is one of the main pre-disposing risk factors for piglet mortality. Management strategies, such as energy supplementation to neonatal piglets, may reduce preweaning mortality. In practice, energy supplementation might be implemented in the farrowing management. Energy supplements may provide energy to neonatal piglets directly as well as improve their colostrum intake. Therefore, the present study investigated the effect of a commercial energy supplement (Vigorol®) to neonatal low birth weight piglets on mortality, weaning weight, daily weight gain as well as the effect on colostrum intake. In the treatment group, 72 very low (**VLBW** < 1.00 kg) and 77 low (1 kg ≤ **LBW** ≤ 1.20 kg) birth weight piglets out of 306 total live-born piglets from 22 litters were orally supplemented at birth and 8 to 12 h after birth. In the control group, 81 VLBW and 74 LBW piglets out of 340 total live-born piglets from 24 litters were not supplemented. Mortality till day 3 was lower (P < 0.001) and tended to be lower (P = 0.07) in supplemented versus control VLBW and LBW piglets, respectively. In general, mortality till day 3 also tended to be lower (P = 0.06) in supplemented piglets. Mortality till day 7 (P < 0.001) and day 21 (P < 0.001) remained lower in supplemented VLBW piglets. No difference was observed regarding LBW and overall mortality till day 7 (P = 0.64; P = 0.24) and day 21 (P = 0.61; P = 0.23). Weaning weights were lower (P = 0.04) in the treatment than in the control group. Daily weight gain (P = 0.42), colostrum intake (P = 0.56), nor colostrum yield (P = 0.21) differed between the groups. Colostrum intake was numerically (P = 0.53) more uniform among litter mates in the treatment versus the control group. This study demonstrated that energy supplementation to neonatal (V)LBW piglets is a way of reducing piglet mortality by providing direct energy, rather than by improving (the uniformity of) colostrum intake.

Key words: colostrum, energy, mortality, neonatal, piglet

INTRODUCTION

Preweaning piglet mortality is an important economic and welfare problem. Crushing, starvation and chilling are the main causes of piglet mortality (Edwards, 2002; Herpin et al., 2002; Alonso-Spilsbury et al., 2007). Early and sufficient energy supply is of utmost importance for neonatal survival (Edwards, 2002; Andersen et al., 2009; Theil et al., 2014b). Neonatal piglets require energy for growth and maintenance. Maintenance includes physical activity and to a great extent thermoregulation (Herpin et al., 2002; Le Dividich et al., 2005). The energy demands of neonatal pigs have to be met by body reserves and by colostrum. However, glycogen reserves are rapidly depleted, body protein catabolism is low during the neonatal period and only a small proportion of the low total fat amount is available for mobilization (Le Dividich et al., 1994; 2005). In addition, selection for increased litter size and leaner carcasses have resulted in less energy reserves at birth (Herpin et al., 1993). Therefore, energy provided by colostrum is imperative for neonatal survival. Colostrum intake may be enhanced by boosters supplying the energy needed to compete with littermates for a functional teat (Le Dividich et al., 2005). Compared to normal birth weight piglets, (very) low birth weight piglets are at particular risk to die as they are less competitive for colostrum intake in addition to their higher energy demands per unit of body weight and lower energy reserves (Herpin et al., 2002; Baxter et al., 2008; Devillers et al., 2011). As the proportion of (very) low birth weight piglets has increased with selection for increased litter size (Quiniou et al., 2002; Beaulieu et al., 2010), strategies are needed to reduce (low birth weight) piglet preweaning mortality.

Several supplements are marketed to improve neonates' energy status and survival rate, however scientific evidence of their efficacy is scarce (De Vos et al., 2014). Therefore, the present study was conducted to investigate the effect of a commercial energy supplement to neonatal (very) low birth weight piglets on mortality, daily weight gain and weaning weight. As energy supplements may enable (very) low birth weight piglets to compete (more) successfully with their heavier littermates for colostrum, considering the crucial role of colostral energy to neonatal survival and regarding the lack of field trials investigating the effect of management routines on colostrum intake, the present study investigated also the effect of supplementation on colostrum intake.

MATERIALS AND METHODS

Study population

The study was performed during July and August 2013 at a commercial farm in Flanders (northern Belgium) with 1700 Pig Improvement Company (PIC) sows in a 2-week batch system. Sows were inseminated with semen from Piétrain boars. They were group housed with 15 animals per pen from day 29 until day 107 of gestation when they were moved to the farrowing house. Day 0 was defined as the day of first insemination. During gestation sows were fed according to their (visual) body condition. On average the total amount of feed was 3 kg·sow-1·day-1. Feeders dropped a small amount of the gestation diet (90% DM, 16% CP, 4% CF, 4% CFib and 6% CA) during five feeding times throughout the day in order to reduce stress at the two feeders per 15 sows. From day 108 of gestation until weaning, sows were individually housed in conventional farrowing crates. Farrowing pens were 2.8 m by 2.3 m. From day 108 of gestation until day 2 of lactation, sows received a transition diet (90% DM, 13% CP, 5% CF, 4% CFib and 5% CA) three times a day (3.3 kg·sow-1·day-1). From day 3 of lactation until weaning, sows received four times a day a lactation diet (91% DM, 14% CP, 6% CF, 3% CFib and 6% CA) of which the amount increased with 0.5 and 1.0 kg per day for primi- and multiparous sows, respectively, till a maximum feed intake around day seven to ten was reached. Sows had free access to fresh drinking water (flow 1.5 to 2 L/min) in the gestation and farrowing unit. Nest building material was not offered to the sows as this was not technically feasible with the slurry system in the farrowing rooms. The ambient temperature in the farrowing house was set to 24°C. Floor heating and infrared lamps were used to create a piglet microclimate of 30°C. Cross fostering to standardize litter size was not allowed before the second day of life, and only between sows within a treatment group. During the trial, only two piglets were cross-fostered between two control sows. Piglet husbandry procedures (*e.g.* placing official ear tags, iron injection) were performed at day three of lactation. Creep feed (91% DM, 19% CP, 8% CF, 3% CFib and 7% CA) was offered from the 3rd day of lactation. Weaning took place at 22 ± 2 days into specialized housings which were emptied and thoroughly cleaned and disinfected before the introduction of a new group as per EU regulations. Sows and piglets were daily checked for health or eating problems.

Experimental design

The experiment was approved by the Ethical Committee of the Faculty of Veterinary Medicine, Ghent University (EC2013/98). Parity and insemination date were taken into account to be uniformly distributed across both treatment groups before entering the farrowing unit. A total of 56 sows were randomly assigned to a treatment or a control group. Sows were continuously supervised 24 h a day throughout one week. Based on occurrence of farrowing during that week and based on a minimum litter size of 10 live-born piglets, 22 and 24 sows were enrolled in the treatment and control group, respectively. Farrowing was not induced and manual birth assistance was only performed when birth interval between two piglets exceeded one hour. Immediately after birth, piglets were dried, got individual trial ear tags and were weighed before first suckling. Very low birth weight (**VLBW**) piglets were defined as live-born piglets with a birth weight less than 1.00 kg. Studies on birth weight define low birth weight piglets as piglets having a birth weight less than 1.00 kg and/or less than the lower quartile of birth weights (Rehfeldt et al., 2008; Michiels et al., 2013). It is well reported that piglets with a birth weight less than 1.00 kg have a high risk to die within 24 h (Quiniou et al., 2002; Quesnel et al., 2008). As the present study aimed to investigate the effect of energy supplementation not only on early mortality, but also on preweaning mortality, performance and colostrum intake, thresholds for low birth weight (**LBW**) piglets were set at 1.00 and 1.20 kg. The upper threshold of 1.20 kg was set according to the lightest half of live-born piglets, based on the birth weight quartiles in a previous study on the present farm (Declerck et al., 2015). In the treatment group VLBW and LBW piglets were supplemented (Vigorol®, Ecuphar, Oostkamp, Belgium) at birth. Piglets were fixed with one hand and the small tube of the pump was carefully inserted in the mouth. One press on the pump corresponded to a release of three g. Piglets were placed back at the same place where they had been taken up (mostly behind the sows' vulva). The VLBW and LBW piglets in the treatment group were supplemented a second time at 8 to 12 h after birth according to the commercial booster instructions. The main components of Vigorol® (80% DM, 0% CP, 67% CF, 0% CFib and 0% CA) are soya oil (330g/kg) and coconut oil (380g/kg). The energy content of the supplement is 2718 kJ/100 g. Fatty acid composition of the product is presented in **Table 1**. The fatty acids are mainly medium chain fatty acids (MCFA) (6 to 12 carbons).

Table 1 *Type, content and percentage of fatty acids in the energy supplement Vigorol® (Ecuphar, Oostkamp, Belgium) used to investigate the effect of energy supplementation to neonatal (very) low birth weight piglets on mortality, weaning weight, daily weight gain and colostrum intake*

Fatty acid	Quantity per 1000 ml Vigorol®, g	% of total fatty acids
Caproic acid (C6:0)	8	1
Caprylic acid (C8:0)	264	29
Capric acid (C10:0)	176	19
Lauric acid (C12:0)	200	22
Myristic acid (C14:0)	76	8
Palmitic acid (C16:0)	44	5
Oleic acid (C18:1)	56	6
Linoleic acid (C18:2)	74	8
Linolenic acid (C18:3)	10	1

Parameters of comparison

From birth till weaning, dead piglets were registered daily each morning. The cumulative live-born mortality at day 3, day 7 and day 21 were calculated and will be further referred to as mortality till day 3, day 7 and day 21. All piglets were individually weighed immediately after birth, 24 h after birth of the first live-born littermate and at the day of weaning. Considering the variation in weaning age, weaning weight was adjusted to an average weaning age of 21 days by Eq. 1 and 2 (Douglas et al., 2013). Daily weight gain was calculated based on the adjusted weaning weight in order to adjust also daily weight gain for a weaning age of 21 days. The adjusted weaning weight and daily weight gain were used for analysis and will be further referred to as weaning weight and daily weight gain. Colostrum intake was calculated by the mechanistic model as described by Theil et al. (2014a). The model is based on 24-h weight gain (WG, g), body weight at birth (BW_b, kg), and duration of colostrum intake (D, min). The equation is the following:-106 + 2.26 WG + 200 BW_b + 0.111 D – 1414 WG/D + 0.0182 WG/BW_b. Colostrum intake from piglets that died during the first 24h of life was not calculated. Colostrum yield was estimated as the sum of the colostrum intake of the piglets.

Litter uniformity and the uniformity of colostrum intake within a litter was evaluated by the coefficient of variation for the birth weight and colostrum intake of all piglets within a litter, respectively.

Daily weight gain = (weaning weight – birth weight) / (age at weaning) (Eq. 1).

Adjusted weaning weight = (daily weight gain x 21) + birth weight (Eq. 2).

Data analysis

All analyses were performed in SPSS version 22.0 (IBM, SPSS statistics for Windows, Armonk, NY: IBM Corp.). Descriptive results are reported as mean ± SEM and range is mentioned between brackets. Normal distribution was evaluated by the descriptives, the Kolmogorov-Smirnov test ($P > 0.01$) and QQ plots. Differences in mortality between treatment groups were tested by chi-square tests. The association between energy supplementation and mortality was quantified by odds ratios (Dohoo et al., 2009). The association between weaning weight, daily weight gain, colostrum intake per piglet, colostrum yield and uniformity of colostrum intake within a litter on the one hand and treatment group and birth weight category on the other hand were investigated using linear mixed regression models. A random sow effect was included to correct for clustering of piglets within litters and to correct for confounding factors at the sow level. Initially, the association between treatment group and each dependent variable was evaluated using univariable linear mixed regression models. Statistical significance in this step was assessed at $P < 0.20$. Secondly, Spearman rank correlations tests were calculated among treatment group and birth weight category. Both could be withheld for further analysis. Then, a multivariable linear regression model was built by a manual stepwise backward model and finally, 2-way interactions were tested. Statistical significance in these two steps was assessed at $P < 0.05$.

RESULTS

Descriptive results

In total, 46 sows with 646 live-born and 45 stillborn piglets were included. The treatment group included 22 sows, 306 live-born and 20 stillborn piglets. These 306 live-born piglets included 72 VLBW and 77 LBW piglets. The control group consisted of 24 sows, 340 live-born and 25 stillborn piglets. Out of these 340 live-born piglets, 81 and 74 were VLBW and LBW piglets, respectively. Sows had a mean parity of 4 ± 0.3 (1 to 9) and a gestation length of 114 ± 0.2 days (111 to 117). Sows had on average 1 ± 0.2 (0 to 4) stillborn piglets. Litter size at birth and at weaning averaged 14 ± 0.3 (10 to 18) and 10 ± 0.4 (5 to 15), respectively. The average piglet birth weight was 1.23 ± 0.028 kg (0.827 to 1.631). The litter birth weight averaged 17.15 ± 0.527 kg (11.30 to 27.36) and the mean variation coefficient of litter birth weight was 22 ± 0.9% (12 to 36). Sow production parameters for treatment and control group are given by **Table 2.** In general, mortality till day 3, day 7 and day 21 averaged 20; 24 and 28%, respectively. Piglets had a mean weaning weight of 5.43 ± 0.066 kg (1.30 to 9.38) and daily weight gain averaged 211 ± 3.1 g (19 to 412). Colostrum intake per piglet and per litter averaged 355 ± 5.7 g (0 to 823) and 4479 ± 148.2 g (2229 to 6922), respectively. The mean uniformity of colostrum intake within a litter was 33 ± 1.7% (12 to 63). Mortality rates, weaning weight, daily weight gain, colostrum intake, colostrum yield and colostrum uniformity for each group and for each birth weight category are summarized by **Table 3** and **Table 4**.

Table 2 *Production parameters from 22 and 24 sows in the treatment versus control group, respectively*

Parameter	Treatment	Control
Parity	5 ± 0.6 (1 - 9)	4 ± 0.4 (1 - 7)
Gestation length, days	114 ± 0.3 (112 - 117)	114 ± 0.3 (111 – 116)
Number of stillborn piglets per sow	1 ± 0.3 (0 - 4)	1 ± 0.3 (0 – 3)
Number of live-born piglets per sow	14 ± 0.5 (10 - 18)	14 ± 0.4 (10 – 18)
Number of weaned piglets per sow	10 ± 0.6 (5 – 15)	10 ± 0.5 (5 – 14)
Piglet birth weight, kg	1.22 ± 0.037	1.23 ± 0.042
	(0.827 – 1.514)	(0.886 – 1.631)
Litter birth weight, kg	16.96 ± 0.811	17.33 ± 0.700
	(11.30 – 26.03)	(11.52 – 27.36)
Litter uniformity? %	21 ± 1.2 (12 – 34)	23 ± 1.4 (12 – 36)

Mortality

Descriptive and statistic results about the influence of supplementation on mortality are summarized in **Table 3**. Regarding VLBW and LBW piglets, the odds to be alive till day 3 was 4.88 ($P < 0.001$) and tended to be 1.94 ($P = 0.07$) times higher in the treatment versus the control group. In general, the odds to be alive till day 3 tended to be 1.46 ($P = 0.06$) times higher in the treatment group than in the control group. The odds to be alive till day 7 and day 21 remained 4.04 ($P < 0.001$) and 3.59 ($P < 0.001$) times higher in supplemented versus control VLBW piglets. Regarding LBW piglets, the odds to be alive till day 7 (0.83; $P = 0.64$) and day 21 (1.21; $P = 0.61$) was not different between treatment and control group. In general, there was neither a difference in odds to survive till day 7 (1.37; $P = 0.24$) and day 21 (1.24; $P = 0.23$) between the treatment and control group.

Table 3 *Descriptives and odds ratios of mortality till day 3, day 7 and day 21 of lactation regarding supplementation versus no supplementation of VLBW and LBW piglets*

Mortality	Treatment	Control	Odds ratio	95% CI	P-value	c^2-value
Mortality day 3, %						
VLBW	17	49	4.88	2.29 - 10.42	**0.00**	18.19
LBW	18	12	1.94	6.94 - 4.01	0.07	3.22
NBW	16	15	0.94	0.52 - 1.69	0.84	0.04
Overall	17	23	1.46	0.99 - 2.17	0.06	3.63
Mortality day 7, %						
VLBW	24	56	4.04	2.01 - 8.13	**0.00**	16.14
LBW	23	20	0.83	0.38 - 1.81	0.64	0.21
NBW	21	16	0.70	0.40 - 1.21	0.20	1.63
Overall	22	26	1.24	0.86 - 1.78	0.24	1.37
Mortality day 21, %						
VLBW	28	58	3.59	1.82 - 7.09	**0.00**	14.17
LBW	23	27	1.21	0.58 - 2.53	0.61	0.27
NBW	25	18	0.66	0.39 - 1.10	0.11	2.52
Overall	25	30	1.24	0.87 - 1.75	0.23	1.43

VLBW = very low birth weight piglet (< 1.00 kg)

LBW = low birth weight piglet (1.00 kg ≤ LBW ≤ 1.20 kg)

NBW= normal birth weight piglet (> 1.20 kg)

Weaning weight, daily weight gain and colostrum intake

The univariable mixed linear regression analyses about the influence of supplementation on weaning weight, daily weight gain, colostrum intake, yield and uniformity are resumed by **Table 4**. Only weaning weight was withheld by univariable analysis ($P = 0.04$) and further analyzed (**Table 5**). Weaning weight was lower in the treatment (5.15 ± 0.091 kg) than in the control group (5.69 ± 0.092 kg) ($P = 0.03$). Weaning weight was also significantly different between the three birth weight categories ($P < 0.001$). There was no significant interaction between the effect of supplementation and birth weight category on weaning weight ($P = 0.21$). There was no difference in daily weight gain ($P = 0.42$) nor colostrum intake ($P = 0.56$) between the treatment and control group. Sow colostrum yield was numerically ($P = 0.21$) lower (4284 ± 191.7 g), but was numerically ($P = 0.53$) more uniform (CV = 32 ± 2.3%) distributed among litter mates in the treatment group compared to a colostrum yield of 4657 ± 220.7 g and a coefficient of variation of 35 ± 2.6% in the control group.

Table 4 *Descriptive statistics and the results of the univariable analyses for different dependent variables with group (treatment versus control) as independent variable obtained from 46 (22 versus 24, respectively) litters and their 646 (306 versus 340, respectively) live-born piglets*

Dependent variable	**Mean ± SEM (range)**		**P-value**
	Treatment	**Control**	
Weaning weight, kg			0.04
VLBW	3.77 ± 0.194 (1.30 – 5.90)	4.57 ± 0.192 (1.71 – 7.61)	
LBW	4.88 ± 0.129 (2.11 – 6.99)	5.17 ± 0.153 (1.69 – 7.11)	
NBW	5.65 ± 0.115 (1.68 – 8.13)	6.14 ± 0.113 (1.90 – 9.38)	
Overall	5.15 ± 0.091 (1.30 – 8.13)	5.69 ± 0.092 (1.69 – 9.38)	
Daily weight gain, g			0.42
VLBW	157 ± 10.6 (32 – 285)	181 ± 9.5 (48 – 345)	
LBW	205 ± 7.0 (54 – 342)	198 ± 7.5 (35 – 278)	
NBW	216 ± 6.0 (19 – 412)	233 ± 5.7 (31 – 412)	
Overall	204 ± 4.4 (19 – 412)	217 ± 4.4 (31 – 412)	
Colostrum intake, g			0.56
VLBW	234 ± 13.8 (39 – 590)	226 ± 16.4 (0 – 520)	
LBW	331 ± 10.8 (89 – 547)	325 ± 13.6 (0 – 596)	
NBW	402 ± 9.8 (0 – 660)	424 ± 10.1 (0 – 823)	
Overall	349 ± 7.7 (0 – 660)	361 ± 8.6 (0 – 823)	
Colostrum yield, kg	4284 ± 191.7 (2423 – 5767)	4657 ± 220.7(2229 – 6922)	0.21
Colostrum uniformity,%	32 ± 2.3 (16 – 59)	35 ± 2.6 (12 – 63)	0.53

VLBW = very low birth weight piglet (< 1.00 kg)

LBW = low birth weight piglet (1.00 kg ≤ LBW ≤ 1.20 kg)

NBW= normal birth weight piglet (> 1.20 kg)

Table 5 *Final results of the multivariable mixed linear regression analysis with weaning weight as dependent variable and group (treatment versus control) and birth weight as independent variables*

	Slope	**SE**	**df**	**LSM**	**P-value**
Intercept	5.69	0.155	52	-	< 0.001
Group					0.03
Treatment	Ref.	-	-	4.84	
Control	0.42	0.203	43	5.26	
BWb category					< 0.001
VLBW	-1.74	0.168	466	4.16	
LBW	-0.81	0.137	466	5.09	
NBW	Ref.	-	-	5.90	
Group x BWb category	-	-	-	-	0.21

BWb= birth weight

VLBW = very low birth weight piglet (< 1.00 kg)

LBW = low birth weight piglet (1.00 kg ≤ LBW ≤ 1.20 kg)

NBW= normal birth weight piglet (> 1.20 kg)

DISCUSSION

It is well established that preweaning mortality is an important welfare and economic problem in pig herds with high-prolific sows. Management can be adjusted to withhold piglet mortality (Andersen et al., 2009), but many other factors (*e.g.* housing, genotype, nutrition) can be addressed to reduce preweaning mortality (Kirkden et al., 2013). Regarding the increasing interest of a sufficient colostrum intake to neonatal survival, the effect of management routines on colostrum intake need to be investigated. To our knowledge, this is the first study investigating the influence of energy supplementation to (V)LBW neonatal piglets on mortality, weaning weight, daily weight gain as well as on colostrum intake.

Mortality

In the present study energy supplementation was an effective method to reduce VLBW piglet mortality. As sufficient energy is needed to survive till day 3 (Theil et al., 2014b), supplementation did improve energy status of neonatal piglets. Boosters may provide direct energy as well as improve colostrum intake. Colostrum intake did not increase in the present study and hence, the supplement might have provided direct energy and spared endogenous fuels. The supplement is energy dense, as the energy supplied by 6 g of the supplement is equal to the energy obtained from 60 g colostrum with an energy content of 260-276kJ/100 g (Theil et al., 2014b). Moreover, the supplement consists mainly of medium chain fatty acids. It is well demonstrated that MCFA are easily utilized as an energy source by neonatal piglets (Wieland et al., 1993; Lee and Chiang, 1994). Hence, the lower VLBW and the tendency to a lower LBW and overall piglet mortality till day 3 might be attributed to the fact that energy requirements were met (to a higher degree) in supplemented piglets. The lower VLBW versus the tendency of lower LBW mortality till day 3 might be attributed to a higher degree of energy deficit in VLBW versus LBW piglets as a decrease of birth weight implies higher energy demands per kg of birth weight because of a higher surface-to-volume ratio (Noblet and Etienne, 1987). Therefore, energy supplementation might have been more crucial to survive in VLBW versus LBW piglets. Furthermore, VLBW mortality remained lower till day 7 and day 21. During early lactation the sow's mammary gland has huge potential for growth. A crucial factor for determining postpartum mammary growth is suckling and milk removal. Factors enhancing milk removal by the piglet are expected to stimulate mammary growth

(Hurley, 2001; Theil et al., 2006; Farmer, 2013). The supplemented piglets may be stronger and more vital to suckle mammary secreta, especially milk as colostrum intake was not different between both groups. Due to a higher milk removal by the supplemented piglets, we may assume that lactation was improved and thereby, VLBW mortality till day 7 and 21 remained lower in the treatment group. In the present study crushing, chilling and starvation were assumed to be the main causes of live-born piglet mortality according to the hypothermia-starvation-crushing complex described by Edwards (2002). Because of practical limitations we were unable to determine the specific underlying cause of death. A clear distinction between the causes of mortality based upon necropsy would give more insight in the observed effect of energy supplementation on mortality. The high preweaning piglet mortality in the present study might be due to the intensive supervision during the trial. Probably, farrowing supervision decreased the number stillbirths in the study, as this was lower than usual in the herd. Probably, some piglets that would have died by intra-partum asphyxia were although live-born thanks to birth assistance. However, vitality and hence, the probability to survive might have been compromised in these piglets as (non-lethal) asphyxia during parturition causes brain damage and weakens piglets (Herpin et al., 1996; Alonso-Spilsbury et al., 2007). On the other hand, continuous supervision 24 h a day throughout one week might have stressed sows and therefore, increased the probability for *e.g.* crushing (Rutherford et al., 2013).

Weaning weight, daily weight gain and colostrum intake

Weaning weight and daily weight gain were consistent with other studies (De Grau et al., 2005; Larriestra et al., 2006; Fix et al., 2010). Energy supplementation did not appear to improve weaning weight. As daily weight gain was not different between both treatment groups, the lower weaning weight in the treatment group is likely the result of the lower preweaning VLBW piglet mortality in the treatment versus the control group. The higher proportion of VLBW piglets at weaning in the treatment group may explain the lower weaning weight in the treatment group as birth weight is positively related with weaning weight (Quiniou et al., 2002; Gondret et al., 2005; Beaulieu et al., 2010).

The estimated average colostrum intake per piglet (355 ± 5.7 g), sow colostrum yield (4479 ± 148.2 g) and colostrum uniformity (33 ± 1.7%) are comparable with other studies (Devillers et al., 2007; Quesnel, 2011; Decaluwé et al., 2013; 2014; Theil et al., 2014a; b). Most

previous studies estimated colostrum intake by the regression equation of Devillers et al. (2004), whereas colostrum intake in this study was estimated by the mechanistic model of Theil et al. (2014a). As Devillers' equation was obtained from bottle-fed piglets, colostrum intake of sow-reared piglets are underestimated (mainly) due to altered physical activity. The equation by Theil et al. (2014a) quantifies accurately colostrum intake of sow-reared piglets with normal suckling and physical activity. Theil et al. (2014a) demonstrated an underestimation of colostrum intake by 30% by using Devillers' equation in sow-reared piglets. As the present study was conducted at a commercial farm with sow-reared piglets the model of Theil et al. (2014a) was used to avoid underestimation and to obtain a much higher precision and accuracy. Colostrum intake depends on the ability of the sow to produce colostrum and on the ability of the piglets to suckle colostrum from the udder (Le Dividich et al., 2005). Colostrum intake may be enhanced by boosters supplying the energy needed to compete with littermates to obtain and defend a functional teat (Le Dividich et al., 2005). However, energy supplementation to neonatal (V)LBW piglets did not improve their colostrum intake in the present study. Despite the fact that fat supplies much more energy than carbohydrate and protein, it is questionable if fat is the most appropriate source of energy to neonatal piglets as they have low lipase activity and fat digestibility. However, the energy supplement in the present study consisted mainly of MCFA, which are easily digested, absorbed and oxidized in neonatal piglets (Gu et al., 2003). We wonder if the interval between the second supply of energy at 8 to 12 h after birth and the second weighing at 24 h after the birth of the first live-born littermate might have been too short to observe an influence on colostrum intake. The lack of any positive effect of supplementation on colostrum intake could also be attributed to the fact that fat supplementation could have reduced appetite, supplemented piglets were satiated and hence, were less likely to search for the udder. However, satiation by the supplement might be ignored as 6 g of the supplement is equivalent to the energy of 60 g colostrum and a voluntary intake of 450 g/kg of birth weight was observed in piglets bottle-fed with colostrum (Devillers et al., 2005). Furthermore, previous studies demonstrated well that factors determining colostrum intake are poorly understood (Farmer and Quesnel, 2009; Devillers et al., 2011; Quesnel, 2011) and hence, it is plausible that methods to improve colostrum intake are hard to find. Colostrum intake is highly variable within litters (Devillers et al., 2007; Quesnel et al., 2012). In the present study, the colostrum intake within a litter was numerically more uniform in the treatment than in the control group. Considering the high proportion of (V)LBW piglets in the present study, further research supplementing a smaller proportion of piglets is needed to know whether or not energy

supplementation of the smallest litter mates helps improve colostrum intake uniformity within a litter. In order to significantly reduce competition and improve uniformity of colostrum intake within a litter, weight differences within a litter can be more important than the absolute birth weight (Milligan et al., 2002; Devillers et al., 2007; Quesnel, 2011). Hence, selection of piglets based on birth weight relative to the litter's mean birth weight instead of selection on their absolute birth weight might be preferred. As the present study was conducted on a commercial farm performing cross-fostering, one threshold of absolute birth weight for all supplemented litters was preferred.

CONCLUSION

In conclusion, energy supplementation to neonatal (V)LBW piglets reduced VLBW piglet preweaning mortality by providing direct energy, rather than by improving colostrum intake. As piglet mortality is an increasing welfare concern in addition to an economic problem and (V)LBW are omnipresent in high-prolific sows, pig producers can implement this measure in their farrowing routines to increase preweaning survival.

LITERATURE CITED

- Alonso-Spilsbury, M.R. Ramírez-Necoechea, M. González-Lozano, D. Mota-Rojas, and M.D. Trujillo-Ortega. 2007. J. Anim. Vet. Adv. 6: 76-86.
- Andersen, I.L, I.A. Haukvik, and K.E. Bøe. 2009. Drying and warming immediately after birth may reduce piglet mortality in loose-housed sows. Animal 3: 592-597.
- Baxter, E.M., S. Jarvis, R.B. D'Eath,, D.W. Ross, S.K. Robson, M. Farish, I.M. Nevvison, A.B. Lawrence, and S.A. Edwards, 2008. Investigating the behavioural and physiological indicators of neonatal survival in pigs. Theriogenology 69: 773-783.
- Decaluwé, R., D. Maes, D., I. Declerck, A. Cools, B. Wuyts, S. De Smet, and G.P.J. Janssens. 2013. Changes in back fat thickness during late gestation predict colostrum yield in sows. Animal 7: 1999-2007.
- Decaluwé, R., D. Maes, B. Wuyts, A. Cools, S. Piepers, and G.P.J. Janssens. 2014. Piglets' colostrum intake associates with daily weight gain and survival until weaning. Livest. Sci. 162: 185-192.
- Declerck, I., J. Dewulf, S. Piepers, R. Decaluwé, and D. Maes. 2015. Sow and litter factors influencing colostrum yield and composition. J. Anim. Sci. 93: 1309-1317.
- de Grau, A., C. Dewey, R. Friendship, K. De Lange. 2005. Observational study of factors associated with nursery pig performance. The Canadian Journal of Veterinary Research 69: 241-245.
- De Vos, M., L. Che, V. Huygelen, S. Willemen, J.. Michiels, S. Van Cruchten, and C. Van Ginneken. 2014. Nutritional interventions to prevent and rear low-birthweight piglets. J. Anim. Phys.and Nutr. 98: 609-619.
- Devillers, N., J. van Milgen, A. Prunier, J. Le Dividich, 2004. Estimation of colostrum intake in the neonatal pig. Anim. Sci. 78: 305-313.
- Devillers N., J. Le Dividich, C. Farmer, A.M. Mounier, M. Lefebvre, and A. Prunier. 2005. Origine et conséquences de la variabilité de la production par la truie et de la consommation de colostrum par les porcelets. J. Rech. Porcine 37: 435-442.
- Devillers, N., C. Farmer, J Le Dividich, and A. Prunier. 2007. Variability of colostrum yield and colostrum intake in pigs. Animal 1: 1033-1041.
- Devillers, N., J. Le Dividich, and A. Prunier. 2011. Influence of colostrum intake on piglet survival and immunity. Animal 5: 1605-1612.
- Dohoo, I., W. Martin, and H. Stryhn. 2009. Veterinary Epidemiological Research. 2nd ed., Ver Inc, Charlottetown, Prince Edwards Island, Canada, p.138.

- Douglas, S.L., S.A. Edwards, E. Sutcliffe, P.W. Knap, and I. Kyriazakis, 2013. Identification of risk factors associated with poor lifetime growth performance in pigs. J. Anim. Sci. 91: 4123-4132.
- Edwards, S.A.. 2002. Perinatal mortality in the pig: environmental or physiological solutions? Livest. Prod. Sci. 78: 3-12.
- Farmer, C.. 2013. Suckling effects in sows: importance for mammary development and productivity. Animal 7: 1964-1968.
- Farmer, C, and H. Quesnel, 2009. Nutritional, hormonal and environmental effects on colostrum in sows. J. Anim. Sci. 87: 56-64.
- Fix, J.S., J.P. Cassady, W.O. Herring, J.W. Holl, M.S. Culbertson, and M.T. See. 2010. Effect of piglet birth weight on body weight, growth, backfat, and longissimus muscle area of commercial market swine. Livestock Science 127: 51-59.
- Gondret, F., L. Lefaucheur, I. Louveau, B. Lebret, X. Pichodo, and Y. Le Cozler. 2005. Influence of piglet birth weight on postnatal growth performance, tissue lipogenic capacity and muscle histological traits at market weight. Livest. Prod. Sci. 93: 137-146.
- Herpin, P., J. Le Dividich, and N. Amaral. 1993. Effect of selection for lean tissue growth on body composition and physiological state of the pig at birth. J. Anim. Sci. 71: 2645-2653.
- Herpin, P., J. Le Dividich, J.C. Hulin, M. Fillaut, F. de Marco, and R. Bertin. 1996. Effects of the level of asphyxia during delivery on viability and early postnatal vitality of newborn pigs. J. Anim. Sci. 96: 2067-2075.
- Herpin, P., Damon, P., Le Dividich, J., 2002. Development of thermoregulation and neonatal survival in pigs. Livest. Prod. Sci. 78: 25-45.
- Hurley, W. 2001. Mammary gland growth in the lactating sow. Livest. Prod. Sci. 70: 149-157.
- Kirkden, R.D., D.M. Broom, I.L. Andersen. 2013. Invited Review: Piglet mortality: Management solutions. J. Anim. Sci. 91: 3361-3389.
- Larriestra, A.J., S. Wattanaphansak, E.J. Neumann, J. Bradford, R.B. Morrison, J. Deen. 2006. Pig characteristics associated with mortality and light exit weight for the nursery phase. Can. Vet. J. 47: 560-566
- Le Dividich, J., P. Herpin, and R.M. Rosario-Ludovino. 1994. Utilization of colostral energy by the newborn pig. J. Anim. Sci. 72: 2082-2089.

- Le Dividich, J., J.A. Rooke, and P. Herpin. 2005. Nutritional and immunological importance of colostrum for the new-born pig. J. Agric. Sci. 143: 469-485.
- Lee, H.F., and S.H. Chiang. 1994. Energy value of medium-chain triglycerides and their efficacy in improving survival of neonatal pigs. J. Anim. Sci. 72: 133-138.
- Michiels, J., M. De Vos, J. Missotten, A. Ovyn, S. De Smet, and C. Van Ginneken, 2013. Maturation of digestive function is retarded and plasma antioxidant capacity lowered in fully weaned low birth weight piglets. Brit. J. Nutr. 109: 65-75.
- Milligan, B.N., D. Fraser, and D.L. Kramer. 2002. Within-litter birth weight variation in the domestic pig and its relation to preweaning survival, weight gain, and variation in weaning weights. Livest. Prod. Sci. 76: 181-191.
- Noblet, J., and M. Etienne. 1987. Body composition, metabolic rate and utilization of milk nutrients in suckling piglets. Reproduction nutrition development 27: 829-839.
- Quesnel, H.. 2011. Colostrum production by sows: variability of colostrum yield and immunoglobulin G concentrations. Animal 5: 1546-1553.
- Quesnel, H., L. Brossard, A. Valancogne, and N. Quiniou. 2008. Influence of some sow characteristics on within-litter variation of piglet birth weight. Animal 2, 1842-1849.
- Quesnel, H., C. Farmer, and N. Devillers. 2012. Colostrum intake: influence on piglet performance and factors of variation. Livest.Sci. 146: 105-114.
- Quiniou, N., J. Dagorn, and D. Gaudré. 2002. Variation of piglets' birth weight and consequences on subsequent performance. Livest. Prod. Sci. 78: 63-70.
- Rehfeldt, C., A. Tuchscherer, M. Hartung, and G. Kuhn. 2008. A second look at the influence of birth weight on carcass and meat quality in pigs. Meat Science 78: 170-175.
- Rutherford, K.M.D., E.M. Baxter, R.B. D'Eath, S.P. Turner, G. Arnott, R. Roehe, B. Ask, P. Sandoe, V.A. Moustsen, F. Thorup, S.A. Edwards, P. Berg and A.B. Lawrence. 2013. The welfare implications of large litter size in the domestic pig I: biological factors. Animal Welfare 22: 199-218.
- Theil, P.K., C. Flummer, W.L. Hurley, N.B. Kristensen, R.L. Labouriau, and M.T. Sorensen. 2014a. Mechanistic model to predict colostrum intake based on deuterium oxide dilution technique data and impact of gestation and prefarrowing diets on piglet intake and sow yield of colostrum. J. Anim. Sci 92: 5507-5519.

- Theil, P.K., C. Lauridsen, and H. Quesnel. 2014b. Neonatal piglet survival: impact of sow nutrition around parturition on fetal glycogen deposition and production and composition of colostrum and transient milk. Animal 8: 1021-1030.
- Theil, P.K., K. Sejrsen,, W.L. Hurley, R. Labouriau, B. Thomsen, and M.T. Sorensen. 2006. Role of suckling in regulating cell turnover and onset and maintenance of lactation in individual mammary glands of sows. J. Anim. Sci. 84: 1691-1698.
- Wieland, T.M., X. Lin, and J. Odle, J.. 1993. Emulsification and fatty-acid length affect the utilization of medium-chain triglycerides by neonatal pigs. J. Anim. Sci. 71: 1869-1874.

Chapter 7

General Discussion

VII. GENERAL DISCUSSION

Insufficient colostrum intake is a major cause of preweaning mortality (Edwards, 2002; Le Dividich et al., 2005; Decaluwé et al., 2014b). Long-term effects of colostrum intake have been suggested (Le Dividich et al., 2005; Devillers et al., 2011; Quesnel et al., 2012, Decaluwé et al., 2014b) and have been confirmed for the first time in the studies presented in the present thesis (**chapter 3**). As colostrum production by the sow is independent from litter size (Devillers et al., 2007; Foisnet et al., 2010; Quesnel, 2011; Decaluwé et al., 2014a), colostrum intake per piglet becomes a critical issue in high-prolific sows. Moreover, sows' colostrum yield and piglets' colostrum intake is not only limited, but also highly variable across sows and piglets, respectively (Le Dividich et al., 2005; Quesnel et al., 2012). Therefore, the present thesis investigated which factors determine sows' colostrum production, colostrum composition (**chapter 4**) and piglets' colostrum intake (**chapter 5**). Regarding the importance of colostrum intake, especially for low birth weight piglets (**chapter 3**), and regarding the positive relationship between colostrum intake and birth weight (**chapter 5**), the effect of energy supplementation to neonatal (very) low birth weight piglets on mortality, daily weight gain, weaning weight as well as colostrum intake was evaluated (**chapter 6**).

In this final chapter, our findings are summarized (**Figure 1**), compared to other research and discussed. We will first focus on the long-term influence of colostrum intake on performance and mortality and its interaction with birth weight. Next, we will discuss on sow and piglet factors determining colostrum yield, composition and colostrum intake. Finally, the impact of energy supplementation to neonatal (very) low birth weight piglets on preweaning performance and mortality as well as on colostrum intake is discussed.

1. LONG-TERM IMPORTANCE OF COLOSTRUM INTAKE ON PERFORMANCE AND MORTALITY

1.1. General

Impact of colostrum

In **Chapter 3** it is shown that colostrum intake and birth weight were positively associated with weaning, intermediate and finishing weights and negatively associated with mortality during the suckling and nursery period. Previous studies observed that colostrum intake was positively related with weight and mortality at weaning and/or at six weeks of age (Devillers et al., 2011; Decaluwé et al., 2014b; Ferrari et al., 2014; Vallet et al., 2015). To our knowledge, this is the first study showing the long-term effects of colostrum intake on performance and mortality.

Mechanisms for colostrum's long-term impact

Being aware that pig performances are influenced by many different factors and physiologic measurements were not performed in the studies presented in this thesis, only hypotheses about the underlying mechanisms for colostrum's impact can be provided. First of all, early and sufficient energy supply is of utmost importance for neonatal survival (Edwards, 2002; Le Dividich et al., 2005; Theil et al., 2014b). As colostrum is the sole external energy source in neonatal piglets, colostrum is a major determinant regarding (early) preweaning performance and mortality (Edwards, 2002; Le Dividich et al., 2005; Devillers et al., 2011; Decaluwé et al. 2014b: Theil et al., 2014b). The observed long-term beneficial impact of colostrum intake on performance and mortality might be attributed to the fact that colostrum does not only supply passive immunity, but is also related with the development towards active immunity (Damm et al., 2002; Rooke and Bland, 2002; Le Dividich et al., 2005; Devillers et al., 2011). Furthermore, neonatal piglets with a high intake of colostrum (energy) are able to engage in teat fights and maintain (regular) suckling and, hence, initiate lactation more properly as milk removal is the best stimulator of lactation in the sow (Hurley, 2001; Theil et al., 2006). High milk intake provides more nutrients to grow, but also a high level of lactogenic immunity. Piglets with a high colostrum and milk intake might be more immunocompetent and

protected, and thus, be less susceptible to (nonlethal) infections. Moreover, colostrum and milk contains various bioactive compounds promoting gastro-intestinal development and nutrient absorption (Wang and Xu, 1996; Xu et al., 2000; Thymann et al., 2006).

1.2. Low birth weight piglets

Birth weight and lifetime performance and mortality

Birth weight affects lifetime performance and mortality (**chapter 3**, Quiniou et al., 2002; Gondret et al., 2005; Rehfeldt and Kuhn, 2006; Beaulieu et al., 2010; Fix et al., 2010; Douglas et al., 2013; Paredes et al., 2013). Low birth weight piglets are disadvantaged when competing with littermates because of their smaller size (Rooke and Bland, 2002), their higher susceptibility to hypothermia by their greater surface-to-volume ratio (Noblet and Etienne, 1987; Herpin et al., 2002), physiological differences (Rooke et al., 2001) and their lower ability to drain and stimulate teats, which induces a lower milk flow (Hurley., 2001; Milligan et al., 2001; Le Dividich et al., 2005; Theil et al., 2006; Devillers et al., 2007). The lower colostrum and milk intake in low birth weight piglets might deteriorate lifetime growth performance and survival. In addition to the lower colostrum and milk intake, low birth weight piglets have fewer muscle fibers compared to their heavier littermates (Rehfeldt et al., 2000; Rehfeldt and Kuhn, 2006). Postnatally, skeletal muscle growth results mainly from myofiber hypertrophy and not from hyperplasia and, therefore, low birth weight piglets are not considered to be able to compensate for growth postnatally according to some authors (Wigmore and Stickland, 1983; Rehfeldt et al., 2000; Gondret et al., 2005; Rehfeldt and Kuhn, 2006; Beaulieu et al., 2010). However, other authors have observed that small piglets are able to catch up in growth (Quiniou et al., 2002; Douglas et al., 2013; Paredes et al., 2013).

Impact of colostrum in low birth weight piglets

Colostrum's beneficial impact was found to be more pronounced (**chapter 3**) when birth weight decreased. First, low birth weight piglets have higher energy demands per kilogram of birth weight (Noblet and Etienne, 1987) and secondly, many biological functions are compromised in low birth weight piglets, such as immune function (Wang et al., 2008),

gastro-intestinal (Xu et al., 1994; Wang et al., 2005; Morise et al., 2008) and brain (Morgane et al., 1993; Gieling et al., 2011) status. Altogether, especially low birth weight piglets might benefit from the supply of colostral energy, immunity and bio-active compounds which promote development of active immunity (Damm et al., 2002; Devillers et al., 2011), gastrointestinal development, nutrient absorption (Wang and Wu, 1996; Xu et al., 2000; Thymann et al., 2006) and brain development (Pierzynowski et al., 2014), respectively. As colostrum's beneficial impact was more pronounced in low birth weight piglets, colostrum intake by low birth weight piglets might be a potential physiological tool to help thrive low birth weight piglets and enable them to catch-up growth and meet body weights of heavier littermates.

2. FACTORS DETERMINING COLOSTRUM YIELD, COMPOSITION, INTAKE

Given the crucial effect of colostral energy on preweaning survival (Edwards, 2002; Le Dividich et al., 2005; Theil et al., 2014b), the importance of colostrum on performance and mortality in the short-term and long-term (**chapter 3**), and the limited and highly variable amount of colostrum produced by the sow (*e.g.* Le Dividich et al., 2005; Devillers et al., 2007), knowledge on factors determining colostrum composition, production and intake is needed to optimize colostrum management and ultimately, maximize lifetime production potential.

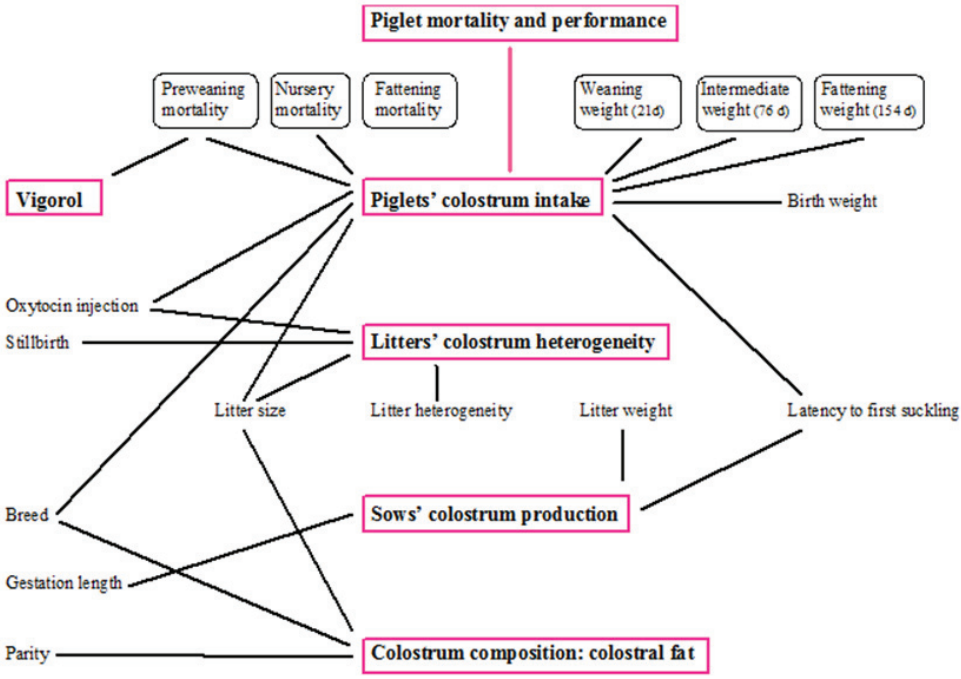

Figure 1. *Schematic overview of the observed significant ($P < 0.05$) relationships in the studies presented in this thesis.*

2.1. Sow predictor factors

Breed

In contrast to other studies, the present thesis included different sow breeds. Hypor sows produced more colostral fat than PIC, Topigs and Danbred sows (**chapter 4**) and hence, selection strategies on colostral fat are possible. In cows (Godden, 2008) and ewes (Pattinson and Thomas, 2004) it has been described that breed is associated with colostrum yield. However, in the study described in **chapter 4** this could not be observed in sows. As a consequence, the observed difference in colostral fat between breed was likely not due to a dilution effect. Moreover, colostrum intake was even higher in Hypor versus Danbred piglets (**chapter 5**) despite the fact that increased colostral fat may depress piglets' colostrum intake (Le Dividich et al., 1997).

Parity

Parity was negatively associated with colostral fat (**chapter 4**) and hence, colostrum from young sows might cover better the relative higher energy demands of low birth weight piglets. Parity was not associated with colostrum yield or intake, which agrees with Le Dividich et al., 2005 and Quesnel, 2011 and disagrees with Devillers et al. (2007) and Decaluwé et al. (2013). The observed relationship with parity by the latter study was attributed to the significant negative correlation between parity and gestation length.

Gestation length

In the present thesis, farrowing induction was not applied and hence, the influence of gestation length was not confounded by parturition induction. In agreement with Devillers et al. (2007), the present study revealed that a shorter gestation length is not necessarily associated with a lower colostrum yield (**chapter 4**). However, Decaluwé et al. (2013) observed a positive relationship between gestation length and colostrum yield and attributed this to decreased vitality and intake in earlier parturitions. Although, in the present thesis, colostrum intake was neither affected by gestation length (**chapter 5**).

Oxytocin injection

Lower and more heterogeneous acquisition of colostrum among littermates was observed in piglets which dam was injected with **oxytocin** during farrowing. The hormones involved in the parturition process are also involved in milk production. Hence, hormonal imbalances resulting in prolonged farrowing and implying the use of oxytocin (Alonso-Spilsbury et al., 2004), may be the underlying mechanism of a lower colostrum production and hence, lower intake. However, the use of oxytocin was not associated with colostrum yield (**chapter 4**) and hence, the lower and more heterogeneous colostrum intake might be linked rather with the consequences (*e.g.* stressing the sow and impairing piglets' vitality, respectively) than with the underlying indication of prolonged farrowing for oxytocin injection.

Stillbirth

Stillbirth was not found to be related with colostrum yield (**chapter 4**), which is in contrast with Quesnel (2011). However, colostrum intake was more heterogeneous in litters with stillbirth. This might be a consequence of intra-partum asphyxia resulting in live-born piglets with compromised vitality in addition to stillborn littermates (Herpin et al., 1996).

2.2. Piglet predictor factors

Litter size, litter weight, birth weight and litter heterogeneity

In agreement with other studies (Devillers et al., 2007; Foisnet et al., 2010; Quesnel, 2011; Decaluwé et al., 2014a), colostrum yield was independent from **litter size** (**chapter 4**) which likely explains the negative relationship between litter size with colostrum intake per piglet and with the heterogeneity of colostrum intake within a litter (colostrum heterogeneity) (**chapter 5**). Therefore, it is of utmost importance to use the available amount of colostrum optimally among piglets by proper management practices (*e.g.* split-suckling), especially in high-prolific sows. In sows with a gestation length of 114 or 115 days, **litter weight** was positively associated with colostrum yield, which agrees with the observations of Devillers et al. (2005) and might be linked with the higher intake of colostrum by higher **birth weights** (**chapter 5**; Devillers et al., 2007; Le Dividich et al., 2005; Tuchscherer et al., 2000). The

positive association between birth weight and colostrum intake is likely linked with the fact that low birth weight piglets are less able to compete. First, they are smaller (Rooke and Bland, 2002). Secondly, they have higher relative energy requirements due to their higher surface-to-body-mass ratio and are therefore more prone to cold stress (Noblet and Etienne, 1987; Herpin et al., 2002). Further, low birth weight piglets differ physiologically from their littermates (Rooke et al., 2001; Michiels et al., 2013) and finally, they lack the ability to extract successfully colostrum from the teats (Milligan et al., 2002; Devillers et al., 2007; Le Dividich et al., 2005). The influence of birth weight on colostrum intake varied across breeds (**chapter 5**). In some breeds, the impact of birth weight on colostrum intake is greater and hence, especially in these breeds, colostrum management should be favored to low birth weight piglets. The fact that low birth weight piglets are disadvantaged can explain why a positive relationship between colostrum and **litter heterogeneity** was observed (**chapter 5**). This latter relationship was more pronounced when oxytocin was applied to the dam (**chapter 5**), which might be linked with the higher risk of asphyxia and impaired vitality by oxytocin (misuse) in heterogeneous litters with more low birth weight piglets as low birth weight piglets are more susceptible to intrapartum asphyxia compared to normal birth weight littermates (Herpin et al., 1996; Pedersen et al., 2011).

Latency to first suckling

The interval between birth and first suckling (**t_{FS}**) was negatively associated with colostrum yield (**chapter 4**) and colostrum intake (**chapter 5**). Some studies reported that colostrum production is independent from suckling as colostrum is produced during late gestation (Theil et al., 2012). However, currently it was stated that it is not exactly known when colostrum is actually produced and probably colostrum is also produced after the onset of farrowing when piglets remove colostrum (Theil, 2015). In the latter scenario, suckling stimulus might be important to stimulate colostrum production. Further, the interval between birth and first suckling (**t_{FS}**) is an important vitality parameter in newborn piglets (Baxter et al., 2008; Tuscherer et al., 2000). Vitality immediately after delivery is the first factor influencing the acquisition of colostrum by piglets (Quesnel, 2011). Piglets with a short versus long t_{FS} were reported to have higher preweaning performance and survival (**chapter 3** and Devillers et al., 2005; Edwards, 2002; Quesnel et al., 2012; Decaluwé et al., 2014b), which might be due to the underlying higher vitality and higher colostrum intake. The observed negative relationship between t_{FS} and colostrum yield and colostrum intake stresses

the importance of vitality in newborn piglets and confirms that measures helping (less vital) piglets get to the udder are beneficial for survival (Andersen et al., 2009; Vasdal et al., 2011). The interaction between t_{FS} and birth weight on colostrum intake (**chapter 5**) indicate that farmers can anticipate the adverse influence of low birth weight on colostrum intake by shortening t_{FS}.

2.3. Sow versus piglet predictors?

Based upon the above, it can be concluded that sow as well as piglet factors influence colostrum yield. This conclusion might however also be partially biased by the used methodology as sows' colostrum yield was estimated as the sum of the colostrum intake by their piglets. We may therefore wonder if this method estimates properly colostrum yield or rather estimate the maximal colostrum intake by piglets. However, it can be assumed that piglets do not consume their full potential as colostrum intake was much higher in bottle-fed versus sow-reared piglets in similar conditions (Devillers, 2004) and as colostrum intake substantially varies between and within litters (Le Dividich et al., 2005). Hence, it is generally accepted that sows limit the colostrum intake by piglets (Farmer et al., 2006; Farmer and Quesnel, 2009; Quesnel et al., 2012) and therefore, estimating sows' colostrum yield as the sum of colostrum intake by their piglets is considered to be appropriate. However, colostrum yield can be underestimated when sows do not allow suckling or when acquisition of colostrum is compromised by udder morphology or teat access (Vasdal and Andersen, 2012; Ocepek et al., 2016). Hence, an alternative method estimating sows' colostrum yield regardless of the piglets' colostrum intake would be very interesting to avoid this kind of underestimation and to distinguish properly sow versus piglet impact on the production of colostrum. Regarding sow versus piglet impact, also knowledge on the exact time of colostrum production (Theil, 2015) is warranted to determine if suckling and, hence piglet vitality, is important to elicit maximum colostrum yield as stated by Fraser (1984). In addition to sow and piglet factors, there are also *e.g.* nutritional and environmental factors (Farmer and Quesnel, 2009) to take into account in relation to colostrum production, composition and intake.

2.4. Devillers versus Theil?

In the present thesis two different models were used to estimate colostrum intake in piglets. At the time of analyzing the first obtained results (chapter 4), only the model of Devillers et al. (2004) was available to assess colostrum intake in commercial conditions. Later a new model was published by Theil et al. (2014a). Theil's model was obtained from sow-reared piglets, whereas the model of Devillers et al. (2004) was established in bottle-fed piglets. As the data of the present thesis (chapter 3, 5, 6) were obtained from sow-reared piglets, the authors and the reviewers preferred to estimate piglets' colostrum intake by Theil et al. (2014a). The data of chapter 4 were re-analyzed with the model of Theil et al. (2014a) and the same results were obtained (unpublished data): colostrum yield was affected by gestation length, the litter weight of the suckling piglets and by the interval between birth and first suckling of the litter. The positive impact of the litter weight of suckling piglets on colostrum yield was observed in all sows, but was less pronounced in sows with a gestation length of 116 days versus sows with a shorter gestation length.

3. EFFECT OF ENERGY SUPPLEMENTATION TO NEONATAL (VERY) LOW BIRTH WEIGHT PIGLETS ON COLOSTRUM INTAKE

Colostrum intake is crucial, especially in low birth weight piglets (**chapter 3**). Unfortunately, colostrum intake decreases if birth weight is reduced (**chapter 5**), due to competitive disadvantage with heavier littermates through *e.g.* higher relative energy demands of low birth weight piglets (Noblet and Etienne, 1987). Therefore, strategies covering these energy demands to some degree may render low birth weight piglets more competitive at the udder and hence, favor colostrum intake to these piglets. This should subsequently reduce the competitive disadvantage and improve the uniformity of colostrum intake across littermates in supplemented litters. To our knowledge, the study described in **chapter 6** evaluated for the first time the effect of a commercial booster on mortality, daily weight gain, weaning weight as well as on colostrum intake.

Mortality at day 3 was lower and tended to be lower in supplemented very low and low birth weight piglets, respectively, which is consistent with Muns et al. (2015). As energy deficit is the major cause of early mortality, energy supplementation did cover the higher relative energy demands in very and low birth weight piglets to some degree. However, (very) low birth weight piglets remained competitive disadvantaged as colostrum intake and uniformity were not increased in supplemented litters. On the one hand, the positive relationship between birth weight and colostrum intake is not only related with the lower energy resources in low birth weight piglets, but also with *e.g.* physiological development. On the other hand, fat supplementation might have reduced appetite (Le Dividich et al., 1997) or the interval between the second supply of energy at 8 to 12 h and the second weighing at 24 h after birth might have been too short to observe an influence of energy supplementation on colostrum intake.

Altogether, this commercial booster to neonatal very low birth weight piglets was found to reduce early preweaning mortality by providing direct energy rather than by improving (the uniformity of) colostrum intake. Other measures, *e.g.* cross-fostering to standardize litters (Straw et al., 1998; Deen and Bilkei, 2004; Milligan et al., 2001) or split suckling (Kyriazakis and Edwards, 1986; Donovan and Dritz, 2000; Muns et al., 2015), might be more promising than energy supplements to anticipate on the competitive disadvantage of low birth weight piglets. However, limited field trials evaluated the effect of management measures, such as cross-fostering and split suckling, on (the uniformity of) colostrum intake by measuring colostrum intake itself. Finally, before advising or implementing this measure, it should be

taken into account that the higher survival rate of very low birth weight was accompanied by lower weaning weights, which might be a critical issue in some (high-prolific) farms.

4. PERSPECTIVES FOR FURTHER RESEARCH

There are different ways to explain the observed long-term importance of colostrum intake on piglet performance and mortality. Further research is needed to elucidate the underlying mechanisms. Future analysis of the bronchio-alveolar lavage fluid and blood samples, which have been taken at 12 and 22 weeks of age during the present thesis, will help to determine the impact of colostrum intake on health parameters.

As the beneficial impact of colostrum intake is more pronounced if birth weight is decreased, future recommendations on piglets' colostrum requirements need to take birth weight into account. The potential role of colostrum to compensate postnatally growth in low birth weight piglets needs to be elucidated in order to reduce management difficulties and batch-system difficulties regarding weight heterogeneity within batches.

A new method to measure colostrum yield independently from the colostrum intake of piglets and more insights in the exact time of colostrum production are warranted to avoid underestimation of colostrum yield and to distinguish sow versus piglet factors determining colostrum yield.

The efficacy of management strategies on colostrum intake needs to be evaluated properly and by measuring colostrum intake.

5. GENERAL CONCLUSIONS OF THE THESIS

From the main results of this thesis, the following conclusions can be drawn:

- Colostrum management is crucial to maximize lifetime production as colostrum intake influences performance and mortality in the short-term and the long-term.

- Colostrum management should favor colostrum intake to low birth weight piglets, especially in high-prolific sows, as
    - the beneficial impact is more pronounced if birth weight is reduced,
    - colostrum intake decreases if birth weight is reduced and
    - colostrum production is independent from litter size.

- Breed affects the level of colostral fat without affecting colostrum yield.

- Unlike colostral fat, protein and lactose levels in colostrum are not affected by sow or litter factors.

- Colostrum yield was higher in sows farrowing at 113 than in sows farrowing at 114 or 115 days of gestation and was higher in litters with shorter latency to first suckling and higher litter weight.

- Oxytocin during delivery should be used cautiously in order to not influence colostrum intake and colostrum heterogeneity, especially in heterogeneous litters.

- Management measures are needed to prevent or counteract the adverse influences of stillbirth, large and heterogeneous litters on colostrum intake and uniformity.

- The negative effect of low birth weight on colostrum intake can be compensated by shortening the interval between birth and first suckling.

- Energy supplementation to neonatal (very) low birth weight piglets might be a way of reducing piglet mortality by providing direct energy, rather than by improving (the uniformity of) colostrum intake.

REFERENCES CITED

- Alonso-Spilsbury M., D. Mota-Rojas, J. Martinez-Burnes, E. Arch, A. Lopez, R. Ramirez-Necoechea, A. Olmos, M.E. Trujillo. 2004. Use of oxytocin in penned sows and its effect on fetal intra-partum asphyxia. Anim. Reprod. Sci. 84: 157-167.
- Andersen, I.L, I.A. Haukvik, K.E. Bøe. 2009. Drying and warming immediately after birth may reduce piglet mortality in loose-housed sows. Animal 3: 592-597.
- Baxter, E.M., S. Jarvis, R.B. D'Eath, D.W. Ross, S.K. Robson, M. Farish, I.M. Nevvison, A.B. Lawrence, and S.A. Edwards. 2008. Investigating the behavioural and physiological indicators of neonatal survival in pigs. Theriogenology 69: 773-783.
- Beaulieu, A.D., J.L. Aalhus , N.H. Williams, J.F. Patience. 2010. Impact of piglet birth weight, birth order, and litter size on subsequent growth performance, carcass quality, muscle composition, and eating quality of pork. J. Anim. Sci. 88: 2767-2778.
- Damm, B.I., N.C. Friggens, J. Nielsen, K.L. Ingvarsten and, L.J. Pedersen. 2002. Factors affecting the transfer of porcine parvovirus antibodies from sow to piglets. Journal of Veterinary Medicine. A Physiology, Pathology, Clinical Medicine 49: 487-495.
- Decaluwé, R., D. Maes, I. Declerck, A. Cools, B. Wuyts, S. De Smet and G.P.J. Janssens. 2013. Changes in back fat thickness during late gestation predict colostrum yield in sows. Animal 7: 1999-2007.
- Decaluwé R., D. Maes, A. Cools, B. Wuyts, S. De Smet, B. Marescau, P.P. De Deyn, and G.P.J. Janssens. 2014a. Effect of peripartal feeding strategy on colostrum yield and composition in sows. J. Anim. Sci. 92: 3557-3567.
- Decaluwé, R., D. Maes, B. Wuyts, A. Cools, S. Piepers, and G.P.J. Janssens. 2014b. Piglets' colostrum intake associates with daily weight gain and survival until weaning. Livest. Sci. 162: 185-192.
- Deen, M.G.H., and G. Bilkei. 2004. Cross-fostering of low birth weight piglets. Livest. Prod. Sci. 90: 279-284.
- Devillers N., J. Le Dividich, C. Farmer, A.M. Mounier, M. Lefebvre, and A. Prunier. 2005. Origine et conséquences de la variabilité de la production par la truie et de la consommation de colostrum par les porcelets. J. Rech. Porcine 37: 435-442.
- Devillers N., J. Le Dividich, and A. Prunier. 2011. Influence of colostrum intake on piglet survival and immunity. Animal 5: 1605-1612.

- Devillers, N. 2004. Variabilité de la production de colostrum chez la truie: origine et conséquences pour la survie du porcelet. PhD Thésis. Université de Rennes, France.
- Donovan, T.S., and S.S. Dritz. 2000. Effect of split-suckling on variation in pig growth from birth to weaning. Journal of the American Veterinary medical association 217: 79-81.
- Douglas, S.L., S.A. Edwards, E. Sutcliffe, P.W. Knap, and I. Kyriazakis. 2013. Identification of risk factors associated with poor lifetime growth performance in pigs. J. Anim. Sci. 91: 4123-4132.
- Edwards, S.A. 2002. Perinatal mortality in the pig: environmental or physiological solutions? Livest. Prod. Sci. 78: 3-12.
- Farmer, C. and H. Quesnel, 2009. Nutritional, hormonal and environmental effects on colostrum in sows. J. Anim. Sci. 87: 56-64.
- Farmer, C., N. Devillers, J.A. Rooke, and J. Le Dividich. 2006. Pig News and Information 27: Review 1-16 or CAB Reviews: Perspectives in Agriculture, Veterinary Science. Nutrition and Natural Resources 1.
- Foisnet, A., C. Farmer, C. David, and H. Quesnel. 2010. Relationships between colostrum production by primiparous sows and sow physiology around parturition. J. Anim. Sci. 88: 1672-1683.
- Ferrari, C.V., P.E. Sbardella, M.L. Bernardi, M.L. Coutinho, I.S. Vaz Jr., I. Wentz, and F.P. Bortolozzo. 2014. Effect of birth weight and colostrum intake on mortality and performance of piglets after cross-fostering in sows of different parities. Prev. Vet. Med. 114: 259-266.
- Fix, J.S., J.P. Cassady, J.W. Holl, W.O. Herring, M.S. Culbertson, and M.T. See. 2010. Effect of piglet birth weight on survival and quality of commercial market swine. Livest. Sci. 132: 98-106.
- Fraser, D. 1984. Some factors influencing the availability of colostrum to piglets. Anim. Prod. 39: 115-123.
- Godden, S. 2008. Colostrum management for dairy calves. Vet. Clin. North Am. Food Anim. Pract. 24: 19-39.
- Gondret, F., L. Lefaucheur, I. Louveau, B. Lebret, X. Pichodo, and Y. Le Cozler. 2005. Influence of piglet birth weight on postnatal growth performance, tissue lipogenic capacity and muscle histological traits at market weight. Livest. Prod. Sci. 93: 137-146.

- Gieling, E.T., S.Y. Park, R.E. Nordquist, and F.J. van der Staay. 2011. Cognitive performance of low- and normal-birth-weight piglets in a spatial hole-board discrimination task. Pediatric Research 71: 71-76.
- Herpin, P., M. Damon, and J. Le Dividich. 2002. Development of thermoregulation and neonatal survival in pigs. Livest. Prod. Sci. 78: 25-45.
- Herpin, P., J. Le Dividich, J.C. Hulin, M. Fillaut, F. De Marco, and R. Bertin. 1996. Effects of the level of asphyxia during delivery on viability at birth and early postnatal vitality of newborn pigs. J. Anim. Sci 74: 2067-2075.
- Hurley, W. 2001. Mammary gland growth in the lactating sow. Livest. Prod. Sci. 70: 149-157.
- Kyriazakis, I., and S.A. Edwards. 1986. The effects of split suckling on behaviour and performance of piglets. Appl. Anim. Beh. Sci. 19: 92.
- Le Dividich, J., P. Herpin, E. Paul, and F. Strullu. 1997. Effect of fat content of colostrum on voluntary colostrum intake and fat utilization in newborn pigs. J. Anim. Sci. 75: 707-713.
- Le Dividich J., J.A. Rooke, and P. Herpin. 2005. Nutritional and immunological importance of colostrum for the new-born pig. J. Agric. Sci. 143: 469-485.
- Michiels, J., M. De Vos, J. Missotten, A. Ovyn, S. De Smet, and C. Van Ginneken, 2013. Maturation of digestive function is retarded and plasma antioxidant capacity lowered in fully weaned low birth weight piglets. Brit. J. Nutr. 109: 65-75.
- Milligan, B.N., D. Fraser, and D.L. Kramer. 2001. The effect of littermate weight on survival, weight gain, and suckling behavior of low birth weight piglets in cross-fostered litters. Journal of swine health production 9: 161-166.
- Morgane, P.J., R. Austinlafrance, J. Bronzino, J. Tonkiss, S. Diazcintra, L. Cintra, T. Kemper, and J.R. Galler. 1993. Prenatal malnutrition and development of the brain. Neuroscience and biobehavioral reviews 17: 91-128.
- Morise, A., I. Louveau, and I. Le Huërou-Luron. 2008. Growth and development of adipose tissue and gut and related endocrine status during early growth in the pig: impact of low birth weight. Animal 2: 73-83.
- Muns, R., X. Manteca, and J. Gasa. Effect of different management techniques to enhance colostrum intake on piglets' growth and mortality. Anim. Welfare 24: 185-192
- Noblet, J., and M. Etienne. 1987. Body composition, metabolic rate and utilization of milk nutrients in suckling piglets. Reprod. Nutr. Dev. 27: 829-839.

- Ocepek, M., I. Andersen-Ranberg, S.A. Edwards, and I.L. Andersen. 2016. Udder characteristics of importance for teat use in purebred and crossbred pigs. J. Anim. Sci. 94: 780-788.
- Paredes, S.P., A.J.M. jansman, M.W.A. Verstegen, A. Awati, W. Buist, L.A. den Harotg, H.M.J. van Hees, N. Quiniou, W.H. Hendriks, and W.J.J. Gerrits. 2013. Analysis of factors to predict piglet body weight at the end of the nursery phase. J. Anim. Sci. 90: 3243-3251.
- Pattinson, S.E., and E.W. Thomas. 2004. The effect of sire breed on colostrum production of crossbred ewes. Livest. Prod. Sci. 86: 47-53.
- Pedersen L.J., P. Berg, G. Jørgensen, and I.L. Andersen. 2011. Neonatal piglet traits of importance for survival in crates and indoor pens. J. Anim. Sci 89: 1207-1218.
- Pierzynowski, S., G. Ushakov, T. Kovalenko, I. Osadchenko, K. Goncharov, P. Gustavsson, O. Prykhodko, J. Wolinski, M., Slupecka, P. Ochniewics, B. Weström, and G. Skibod. 2014. Impact of colostrum and plasma immunoglobulin intake on hippocampus structure during early postnatal development in pigs. Int. J. Dev. Neurosci. 35: 64-71.
- Quesnel, H. 2011. Colostrum production by sows: variability of colostrum yield and immunoglobulin G concentrations. Animal 5: 1546-1553.
- Quesnel, H., C. Farmer, and N. Devillers. 2012. Colostrum intake: influence on piglet performance and factors of variation. Livest. Sci. 146: 105-114.
- Quiniou, N., J. Dagorn, and D. Gaudré. 2002. Variation of piglets' birth weight and consequences on subsequent performance. Livest. Prod. Sci. 78:63-70.
- Rehfeldt, C., I. Fiedler, G. Dietl, and K. Ender. 2000. Myogenesis and postnatal skeletal muscle cell growth as influenced by selection. Livest. Prod. Sci. 66: 177-188.
- Rehfeldt, C., and G. Kuhn. 2006. Consequences of birth weight for postnatal growth performance and carcass quality in pigs as related to myogenesis. J. Anim. Sci. 84: E113.
- Rooke, J.A., and I.M. Bland. 2002. The acquisition of passive immunity in the newborn piglet. Livest. Prod. Sci. 78: 13-23.
- Rooke, J.A., P. Penny, P.C. Penn, G.W. Horgan, A.M. Finch, S.A. Edards, A.G. Sinclair, S. Pkiyach, and R. Cordoba. 2001. The effect of feeding salmon oil to sows throughout pregnancy on pre-weaning mortality of piglets. Anim. Sci. 73: 489-500.
- Straw, B.E., C.E. Dewey, and E.J. Bürgi. 1998. Patterns of cross-fostering and piglet mortality on commercial US and Canadian swine farms. Prev. Vet. Med. 33: 83-89.

- Theil, P.K., M.O. Nielsen, M.T. Sorensen, and C. Lauridsen. 2012. Lactation, milk and suckling. In: K. E. Bach Knudsen, N. J. Kjeldsen, H. D. Poulsen and B. B. Jensen, editors, Nutritional physiology of pigs. Danish Pig Research Centre, Copenhagen. p. 1-47.
- Theil, P.K. 2015. Transition feeding of sows. In: C. Farmer, editor, The gestating and lactating sow. Wageningen Academic Publishers, Wageningen, The Netherlands. P 147-172.
- Theil, P.K., C. Flummer, W.L. Hurley, N.B. Kristensen, R.L. Labouriau, and M.T. Sorensen. 2014a. Mechanistic model to predict colostrum intake based on deuterium oxide dilution technique data and impact of gestation and prefarrowing diets on piglet intake and sow yield of colostrum. J. Anim. Sci 92: 5507-5519.
- Theil, P.K., C. Lauridsen, and H. Quesnel. 2014b. Neonatal piglet survival: Impact of sow nutrition around parturition on fetal glycogen deposition and production and composition of colostrum and transient milk. Animal 8: 1021-1030.
- Theil, P.K., K. Sejrsen, W.L. Hurley, R. Labouriau, B. Thomsen, and M.T. Sorensen. 2006. Role of suckling in regulating cell turnover and onset and maintenance of lactation in individual mammary glands of sows. J. Anim. Sci. 84: 1691-1698.
- Thymann, T., D.G. Burrin, K.A. Tappenden, C.R. Bjornvaad, S.K. Jensen, and P.T. Sangild. 2006. Formula-feeding reduces lactose digestive capacity in neonatal pigs. Br. J. Nutr. 95: 1075-1081.
- Tuchscherer, M., B. Puppe, A. Tuchscherer, and U. Tiemann. 2000. Early identification of neonates at risk: traits of newborn piglets with respect to survival. Theriogenology 54: 371-388.
- Vallet, J.L., J.R. Miles, L.A. Rempel, D.J. Nonneman, and C.A. Lents. 2015. Relationships between day one piglet serum immunoglobulin immunocrit and subsequent growth, puberty attainment, litter size, and lactation performance. J. Anim. Sci. 93: 2722-2729.
- Vasdal, G., and I.L. Larsen. 2012. A note on teat accessibility and sow parity – consequences for newborn piglets. Livest. Sci. 146: 91-94.
- Vasdal, G., I. Østensen, M. Melišová, and, B. Bozděchová. 2011. Management routines at the time of farrowing-effects on teat success and postnatal piglet mortality from loose housed sows. Livest. Sci. 136: 225-231.

- Wang, J.J., L.X. Chen, D.F. Li, Y.L. Yin, X.Q. Wang, P. Li, L.J. Dangott, W.X. Hu, and G.Y. Wu. 2008. Intrauterine growth restriction affects the proteomes of the small intestine, liver, and skeletal muscle in newborn pigs. J. Nutr. 138: 60-66.
- Wang, T., Y.J. Huo, R.J. Xu, and R.J. Hutz. 2005. Effects of intrauterine growth retardation on development of the gastrointestinal tract in neonatal pigs. Biology of the neonate 88: 66-72.
- Wigmore, P.M., and N.C. Stickland. 1983. Muscle development in large and small pig fetuses. J. Anat. 137: 235-245.
- Wang, T., and R. J. Xu. 1996. Effects of colostrum feeding on intestinal development in newborn pigs. Biol. Neonate 70: 339-348.
- Xu, R.J., D.J. Mellor, M.J. Birtles, G.W. Reynolds, and H.V. Simpson. 1994. Impact of intrauterine growth retardation on the gastrointestinal tract and the pancreas in newborn pigs. Journal of pediatric gastroenterology and nutrition 18: 231-240.
- Xu, R.J., F. Wang, S.H. Zhang. 2000. Postnatal adaptation of the gastrointestinal tract in neonatal pigs: a possible role of milk-borne growth factors. Livest. Prod. Sci. 66: 95-107.

Summary

SUMMARY

By the introduction of high-prolific sow breeds, average birth weight and litter uniformity decreased along with the increase of litter size. Large litters imply also lower colostrum intake per piglet as colostrum production is independent from litter size. Altogether, large litters compromise birth weight and colostrum intake, which largely determine preweaning mortality and performance. Hence, farmers are faced lower preweaning survival and with poor weaning weights. Therefore, it is of utmost importance to optimize colostrum management in high-prolific herds.

In order to understand colostrum's potential beneficial impact, to optimize colostrum management and to find strategies improving colostrum intake, survival and performance, current information about the synthesis, the composition, the functions of colostrum, the factors determining colostrum yield, composition and intake and finally, information about preweaning mortality and performance is summarized by **chapter 1.**

So far, long-term effects of colostrum intake have not been reported. Moreover, a lot of variation regarding colostrum production, composition and intake remains to be elucidated, *e.g.* the influence of genetics, gestation length, birth assistance and commercial boosters is still not (clearly) determined. The present thesis aimed (**chapter 2**) to investigate the influence of colostrum in the short- as well as the long-term, to investigate factors determining colostrum yield, composition and intake and to investigate the effect of energy supplementation to (very) low birth weight piglets on preweaning performance and mortality as well as on colostrum intake.

The study described by **chapter 3** aimed to investigate the short-term as well as the long-term influence of colostrum intake on performance and mortality in commercial pig herds. In total, 1,455 live-born piglets from 100 sows on ten commercial pig herds were followed from birth till 22 weeks of age. Pigs were individually weighted at birth, at weaning (21 days of age), at onset (76 days of age, intermediate weight), and during the fattening period (154 days of age, finishing weight). In addition to colostrum intake as main predictor of interest, other predictor

variables were also tested, namely birth weight, birth order, sex, breed, and the interval between birth and first suckling (t_{FS}). Colostrum intake and birth weight were positively associated with weaning ($P < 0.001$), intermediate ($P < 0.001$), and finishing ($P < 0.001$) weights. Furthermore, higher colostrum intake is more beneficial to weaning ($P < 0.001$), intermediate ($P < 0.001$), and finishing ($P = 0.02$) weights if birth weight decreased. Birth order was positively associated with weight at each measurement time ($P = 0.01$). Sex affected only finishing weight ($P < 0.001$). Some breeds differed in piglets' weight at onset or during the fattening period. The association between t_{FS} and weaning weight differed by breed. Preweaning mortality was negatively associated with colostrum intake ($P < 0.001$) and birth weight ($P < 0.001$). Mortality during the nursery period was negatively associated with colostrum intake ($P < 0.001$) and birth weight ($P = 0.002$). The negative association between colostrum intake and mortality during the suckling ($P < 0.001$) and the nursery ($P = 0.008$) periods was more pronounced if birth weight decreased. In conclusion, colostrum intake significantly influences piglets' short-term and long-term performance and mortality and hence, colostrum management is the key to maximize lifetime production potential in sows and pigs. Moreover, colostrum management should guarantee sufficient colostrum intake by low birth weight piglets as colostrum intake is especially beneficial in low birth weight piglets.

In order to optimize colostrum management and regarding the important role of colostral energy for early survival, the aims of **chapter 4** were to investigate which factors determine colostrum yield and its nutritional composition. Colostrum yield of 100 sows was estimated by the colostrum intake of their piglets. Colostrum samples were collected 3 h after the onset of parturition from 91 sows and were analyzed by LactoScope Fourier transform infrared spectroscopy for fat, protein and lactose. Sows with a gestation length of 113 days had a higher colostrum yield (4,178 ± 506 g) than sows with a gestation length of 114 to 115 days (3,342 ± 107 g; $P = 0.04$). An interaction between the litter birth weight of suckling piglets and gestation length was observed. In sows with a gestation length of 114 to 115 days, colostrum yield increased with higher litter birth weight of the suckling piglets. A shorter interval between birth and first suckling of the litter was related to a higher colostrum yield ($P < 0.01$). The percentage of fat in colostrum was higher in Hypor sows (6.35 ± 0.51) than in PIC (4.98 ± 0.27; $P = 0.001$), Topigs (5.05 ± 0.14; $P < 0.001$) and Danbred (5.34 ± 0.22; $P < 0.001$) sows. The percentage of fat in colostrum was negatively associated with parity ($P =$

0.02) and positively associated with the number of live-born piglets (P = 0.03). The percentages of colostral protein and lactose were not significantly associated with any factor. In conclusion, colostrum yield is found to be significantly affected by t_{FS}, gestation length and the interaction between gestation length and litter weight, whereas colostral fat was significantly affected by other factors, namely by sow breed, parity and litter size.

Chapter 5 aimed to unravel the factors explaining the variation in piglets' colostrum intake between and within litters. A total of 1,937 live-born piglets from 135 litters from ten commercial herds were included. Colostrum intake was affected by breed and was lower when oxytocin was administered to the sow during parturition (P = 0.001) and with increased litter size (P < 0.001). It was higher when the interval between birth and first suckling decreased (t_{FS}, P < 0.001). Colostrum intake was positively influenced by birth weight (P < 0.001) and this association was more pronounced in Topigs (P = 0.03) and Hypor (P = 0.03) than in Danbred sows. The positive relationship between colostrum intake and birth weight was more pronounced when t_{FS} lasted longer (P = 0.009). Colostrum heterogeneity was calculated by the coefficient of variation of colostrum intake within a litter. Colostrum heterogeneity increased if oxytocin was applied during farrowing (P = 0.004) and if stillbirth was presented (P = 0.006). Colostrum heterogeneity was positively associated with litter size (P < 0.001) and litter heterogeneity (P = 0.01). The positive relationship between colostrum and litter heterogeneity was more pronounced if oxytocin was applied during farrowing (P = 0.04). In conclusion, oxytocin should be used cautiously in sows during farrowing regarding colostrum intake and heterogeneity. Proper management practices should prevent or counteract the adverse influences of stillbirth (*e.g.* parturition supervision), and large and heterogeneous litters (*e.g.* on colostrum intake and heterogeneity. The study confirmed the expected association between birth weight and colostrum intake and indicated that the impact of birth weight on colostrum intake was different among breeds and dependent on piglets' latency to first suckling. Hence, colostrum management should focus on low birth weight piglets, especially in some breeds, and low colostrum intake in low birth weight piglets can be counteracted by shortening t_{FS} (*e.g.* drying and placing at the udder).

By **chapter 6**, the effect of a commercial booster to neonatal (very) low birth weight piglets was investigated on preweaning mortality, daily weight gain, weaning weight as well as colostrum intake. In the treatment group, 72 very low (VLBW < 1.00 kg) and 77 low (1 kg ≤ LBW ≤ 1.20 kg) birth weight piglets out of 306 total live-born piglets from 22 litters were orally supplemented at birth and 8 to 12 h after birth. In the control group, 81 VLBW and 74 LBW piglets out of 340 total live-born piglets from 24 litters were not supplemented. Mortality till day 3 was lower ($P < 0.001$) and tended to be lower ($P = 0.07$) in supplemented versus control VLBW and LBW piglets, respectively. In general, mortality till day 3 also tended to be lower ($P = 0.06$) in supplemented piglets. Mortality till day 7 ($P < 0.001$) and day 21 ($P < 0.001$) remained lower in supplemented VLBW piglets. No difference was observed regarding LBW and overall mortality till day 7 ($P = 0.64$; $P = 0.24$) and day 21 ($P = 0.61$; $P = 0.23$). Weaning weights were lower ($P = 0.04$) in the treatment than in the control group. Daily weight gain ($P = 0.42$), colostrum intake ($P = 0.56$), nor colostrum yield ($P = 0.21$) differed between the groups. Colostrum intake was numerically ($P = 0.53$) more uniform among litter mates in the treatment versus the control group. This study demonstrated that energy supplementation to neonatal (V)LBW piglets is a way of reducing piglet mortality by providing direct energy, rather than by improving (the uniformity of) colostrum intake.

Finally, the main results of the thesis were summarized, compared to research and discussed in **chapter 7**.

Samenvatting

SAMENVATTING

Door het inzetten van hoogproductieve zeugenlijnen is de gemiddelde toomgrootte de afgelopen jaren sterk toegenomen. De selectie op toomgrootte heeft weliswaar geresulteerd in grotere tomen, maar met een lager gemiddeld geboortegewicht en minder toomuniformiteit. In tegenstelling tot de melkproductie, is de biestproductie onafhankelijk van de toomgrootte. Bijgevolg is er minder biest per big beschikbaar in grote tomen. Aangezien naast geboortegewicht ook biestopname uitermate belangrijk is voor groei en uitval, is er een trend van lagere speengewichten en hogere uitval in de kraamstal sinds de introductie van hoogproductieve zeugenlijnen. Daarom is het uitermate belangrijk om het biestmanagement op hoogproductieve bedrijven te optimaliseren.

Om het belang van biest te begrijpen, om tot een optimaal biestmanagement te komen en finaal groei, overleving en biestopname te verbeteren, werd de beschikbare informatie inzake de productie, de samenstelling, de functies en de factoren determinerend voor biestproductie en –opname samen met groei en uitval in de kraamstal samengevat in **hoofdstuk 1**.

Tot op heden is er geen informatie over het belang van biest op lange termijn beschikbaar. Bovendien blijkt dat de grote variatie in biestproductie, -samenstelling en –opname nog grotendeels onverklaard is en dat de rol van *bv.* genetica, drachtduur, geboortehulp en managementmaatregelen nog niet (volledig) gekend is. De doelstellingen van deze thesis waren het belang van biest op korte en lange termijn te bestuderen, meer inzicht in biestproductie, -samenstelling en –opname te verwerven en het effect van energiesupplementatie op *o.a.* biestopname na te gaan (**hoofdstuk 2**).

In een eerste studie werd de impact van biest op groei en uitval zowel op korte als op lange termijn onderzocht (**hoofdstuk 3**). In totaal werden er 1,455 levend geboren biggen afkomstig van 100 zeugen van tien commerciële varkensbedrijven van geboorte tot de leeftijd van 22 weken opgevolgd. De varkens werden individueel gewogen bij geboorte, bij spenen (21 dagen leeftijd, speengewicht), bij opzet (76 dagen leeftijd, opzetgewicht) en tijdens afmest (154 dagen leeftijd, afmestgewicht). Naast biestopname als hoofdparameter, werden ook de impact

van geboortegewicht, geboorte-rangnummer, geslacht, ras en het interval tussen geboorte en eerste zuigbeurt op groei en uitval onderzocht. Biestopname en geboortegewicht waren positief gerelateerd met speen- ($P < 0.001$), opzet- ($P < 0.001$) en afmestgewicht ($P < 0.001$). Bovendien bleek dat de positieve invloed van biestopname op speen- ($P < 0.001$), opzet- ($P < 0.001$) en afmestgewicht ($P < 0.001$) groter werd naarmate het geboortegewicht afnam. Geboorterangummer was positief gerelateerd met het gewicht op elk tijdstip ($P = 0.01$). Geslacht was enkel van invloed op afmestgewicht ($P < 0.001$). Sommige rassen hadden een significant verschillend opzet- of afmestgewicht. De relatie tussen het interval tussen geboorte en eerste zuigbeurt en het speengewicht varieerde naargelang het ras. Uitval in de kraamstal en uitval op de batterij waren negatief gerelateerd met biestopname ($P < 0.001$; $P < 0.001$) en geboortegewicht ($P < 0.001$; $P = 0.02$). De negatieve relatie tussen biestopname en sterfte in de kraamstal en op de batterij was meer uitgesproken naarmate het geboortegewicht afnam. Samenvattend toont deze studie aan dat biestopname de groei en uitval van biggen significant beïnvloedt en dit zowel op korte als op lange termijn. Bijgevolg vormt biestmanagement de basis om het productiepotentieel van zeug en biggen maximaal te benutten. Een goed biestbeleid moet gericht zijn op voldoende biestopname bij lichte biggen, gezien het relatief belang van biest toeneemt bij dalend geboortegewicht.

Met het oog op optimaal biestmanagement en het cruciaal belang van energie in biest voor overleving, werd er in **hoofdstuk 4** nagegaan welke factoren bepalend zijn voor biestproductie en –samenstelling. De biestproductie van 100 zeugen werd geschat aan de hand van de biestopname van hun biggen. Van 91 zeugen werd biest verzameld drie uur na aanvang van de partus en geanalyseerd met LactoScope Fourier transform infrared spectroscopie op vet, eiwit en lactose. Zeugen met een drachtduur van 113 dagen produceerden meer biest (4,178 ± 506 g) dan zeugen met een drachtduur van 114 tot 115 dagen (3,342 ± 107 g; $P = 0.04$). Er werd een interactie tussen toomgewicht en drachtduur vastgesteld. Zeugen met een drachtduur van 114 tot 115 dagen produceerden meer biest bij toename van het geboortegewicht. Een korter interval tussen geboorte en eerste zuigbeurt was gerelateerd met een hogere biestgift ($P < 0.01$). Het percentage vet in biest was hoger bij Hypor zeugen (6.35 ± 0.51) dan bij PIC (4.98 ± 0.27; $P = 0.001$), Topigs (5.05 ± 0.14; $P < 0.001$) en Danbred (5.34 ± 0.22; $P < 0.001$) zeugen. Het vetgehalte was negatief geassocieerd met pariteit ($P = 0.02$) en positief met het aantal levendgeboren biggen ($P = 0.03$). Het percentage eiwit en lactose in biest was met geen enkele factor significant geassocieerd.

In deze studie werd vastgesteld dat biestproductie gerelateerd is met het gemiddelde interval tussen geboorte en eerste zuigbeurt van de toom, met drachtduur en de interactie tussen drachtduur en toomgewicht, terwijl het vetpercentage door andere factoren bepaald wordt, namelijk zeugenlijn, pariteit en toomgrootte.

In **hoofdstuk 5** werd onderzocht welke factoren de variatie in biestopname tussen en binnen tomen verklaren. Er werden hiervoor 1,937 levendgeboren biggen afkomstig van 135 tomen van tien commerciële bedrijven bestudeerd. Biestopname varieerde tussen de verschillende rassen en nam af wanneer er oxytocine tijdens het werpen aan de zeug werd toegediend (P = 0.001) en bij toenemende toomgrootte ($P < 0.001$). Biestopname nam toe wanneer het interval tussen geboorte en eerste zuigbeurt afnam ($P < 0.001$). Verder was biestopname positief gerelateerd met geboortegewicht en dit vooral bij biggen van Topigs (P = 0.03) en Hypor (P = 0.03) zeugen versus bigggen van Danbred zeugen. Het positief verband tussen biestopname en geboortegewicht was meer uitgesproken bij toenemend interval tussen geboorte en eerste zuigbeurt (P = 0.009). De variatie van biestopname binnen een toom, of biestheterogeniteit, werd berekend aan de hand van de variatiecoëfficiënt van de biestopname van de biggen binnen één toom. Biestheterogeniteit nam toe bij toediening van oxytocine aan de werpende zeug (P = 0.004) en bij doodgeboorte (P = 0.006). Biestheterogeniteit was positief geassocieerd met toomgrootte ($P < 0.001$) en toomheterogeniteit (P = 0.01). De positieve relatie tussen biest- en toomheterogeniteit was meer uitgesproken wanneer er oxytocine tijdens de partus aan de zeug werd toegediend (P = 0.04). Oxytocine moet dus met de nodige voorzichtigheid aangewend worden tijdens de partus, aangezien het nefast blijkt te zijn voor (uniforme) biestopname. Specifieke managementmaatregelen moeten de nadelige gevolgen van doodgeboorte (bv. partustoezicht), en grote en heterogene tomen (bv. alternerend zogen) voorkomen of teniet doen. Deze studie bevestigde dat geboortegewicht negatief gerelateerd is met biestopname en dat deze impact van geboortegewicht op biestopname verschillend is naargelang het ras en het tijdsinterval tussen geboorte en eerste zuigbeurt. Hieruit blijkt dat biestmanagement zich vooral moet richten op de biestopname bij lichte biggen, en dit vooral bij sommige rassen en dat de lagere biestopname bij lichte biggen gecompenseerd kan worden door het interval tussen geboorte en eerste zuigbeurt te beperken (bv. biggen drogen en bij de uier plaatsen).

In **hoofdstuk 6** werd het effect van een commerciële booster aan pasgeboren (heel) lichte biggen op uitval en dagelijkse groei in de kraamstal, op speengewicht en op biestopname onderzocht. In de behandelingsgroep werden er van de 306 levend geboren biggen in 22 tomen 72 heel lichte (VLBW < 1.00 kg) en 77 lichte (1 kg ≤ LBW ≤ 1.20 kg) biggen oraal gesupplementeerd bij de geboorte en 8 tot 12 uur na de geboorte. In de controlegroep werden van de 340 levendgeboren biggen in 24 tomen, 81 VLBW en 74 LBW biggen niet gesupplementeerd. De uitval tot dag 3 was significant ($P < 0.001$) en numeriek ($P = 0.07$) lager in respectievelijk gesupplementeerde versus controle VLBW en LBW biggen. Ook de algemene uitval tot dag 3 was numeriek (P = 0.06) lager in gesupplementeerde biggen. De uitval tot dag 7 ($P < 0.001$) en tot dag 21 ($P < 0.001$) bleef lager in gesupplementeerde VLBW biggen. Er werd geen verschil in uitval waargenomen van lichte biggen of van alle biggen tot dag 7 ($P = 0.64$; $P = 0.24$) en tot dag 21 ($P = 0.61$; $P = 0.23$). De speengewichten waren lager ($P = 0.04$) in de behandelingsgroep dan in de controlegroep. De dagelijkse groei ($P = 0.42$), biestopname ($P = 0.56$), noch biestproductie ($P = 0.53$) waren verschillend tussen de groepen. Biestopname was numeriek ($P = 0.53$) uniformer tussen toomgenoten in de behandelings- verus de controlegroep. Deze studie toont aan dat energiesupplementatie van pasgeboren (heel) lichte biggen een manier kan zijn om biggensterfte in de kraamstal te reduceren en dit eerder door het verschaffen van extra energie en niet zozeer door de (uniformiteit in) biestopname te verbeteren.

In hoofdstuk 7 worden de belangrijkste bevindingen besproken en vergeleken met ander onderzoek.

Curriculum Vitae

CURRICULUM VITAE

Ilse Declerck werd op 7 juni 1986 geboren te Waregem. Zij behaalde in 2004 haar diploma hoger secundair onderwijs in de richting Wetenschappen-Wiskunde aan het Onze-Lieve-Vrouw Hemelvaartinstituut te Waregem. Vervolgens vatte ze de studie Diergeneeskunde aan te Gent. In 2010 studeerde ze af als master in de Diergeneeskunde Optie Herkauwers, Keuzevak Varken met grote onderscheiding.

In november 2010 trad ze in dienst als assisterend academisch personeel bij de Eenheid Varkensgezondheidszorg en de Eenheid Veterinaire Epidemiologie op de vakgroep Voortplanting, Verloskunde en Bedrijfsdiergeneeskunde aan de Faculteit Diergeneeskunde van de UGent. Haar onderzoek focust op biestopname en biestproductie op het hoogproductieve zeugenbedrijf met als promotoren prof. dr. Dominiek Maes en prof. dr. Jeroen Dewulf. Ze was actief in de Buitenpraktijk en Bedrijfsbegeleiding Varken, stond mee in voor de opleiding van de laatstejaarsstudenten optie Varken-Pluimvee-Konijn en voerde bedrijfsbezoeken en projecten uit in het kader van Veepeiler Varken. Daarnaast hielp ze bij de nacht- en weekenddiensten van de kliniek Verloskunde Rund en van de Buitenpraktijk Rund.

Ilse volgde verscheidene specialisatiecursussen. Ze behaalde in juli 2013 het diploma Vakdierenarts Varken aan de Faculteit Diergeneeskunde van de UGent. Ilse is auteur en co-auteur van meerdere wetenschappelijke publicaties en was spreker op nationale en internationale studiedagen en congressen.

Bibliography

BIBLIOGRAPHY

1. PUBLICATIONS

Decaluwé, R., G.P.J. Janssens, **I. Declerck**, A. de Kruif, and D. Maes. 2012. Induction of parturition in the sow. Vlaams Diergeneeskundig Tijdschrift 81:158-165.

Decaluwé, R., D. Maes, **I. Declerck**, A. Cools, B. Wuyts, S. De Smet, and G.P.J. Janssens. 2013. Changes in backfat thickness during late gestation predict colostrum yield in sows. Animal 7:1999-2007.

Declerck, I., J. Dewulf, R. Decaluwé, and D. Maes. 2016. Effects of energy supplementation to neonatal (very) low birth weight piglets on mortality, daily weight gain, weaning weight and colostrum intake. Livest. Sc. 183:48-53.

Declerck, I., J. Dewulf, S. Piepers, R. Decaluwé, and D. Maes. 2015. Sow and litter factors influencing colostrum yield and nutritional composition. J. Anim. Sci. 93:1309-1317.

Declerck, I., J. Dewulf, S. Sarrazin, and D. Maes. 2016. Long-term effects of colostrum intake in piglet mortality and performance. J. Anim. Sci. 94:1-11.

Declerck, I., J. Dewulf, S. Sarrazin, A. Michiels, and D. Maes. The importance of birth weight and colostrum intake on health parameters during piglets' lifetime. In preparation.

Declerck, I., S. Sarrazin, J. Dewulf, and D. Maes. 2017. Sow and piglets factors determining variation of colostrum intake between and within litters. Animal, accepted.

Declerck, I., S. Van Gansbeke, G. Opsomer, S. De Vliegher, A. de Kruif, and D. Maes. 2012. Some critical aspects of housing dairy cattle. Vlaams Diergeneeskundig Tijdschrift 81: 149-157.

Dipongkor, S., R. Del Pozo Sacristan, N. Van Renne, L. Huang, R. Decaluwé, A. Michiels, A. Lopez Rodriguez, M. J. Rodriguez, M.G. Duran, **I. Declerck**, D. Maes, and H.J. Nauwynck. 2014. Anti-porcine circovirus type 2 (PCV2) antibody placental barrier leakage from sow to fetus: impact of the diagnosis of the intra-uterine PCVV2 infection. Vir. Sin. 29: 136-138.

2. ORAL AND POSTER PRESENTATIONS

Declerck, I., J. Dewulf, S. Piepers, R. Decaluwé, and D. Maes. 2012. 4th ESPHM, Bruges, Belgium.

Declerck, I., S. Piepers, J. Dewulf, A. de Kruif, and D. Maes. 2012. Influence of birth weight and colostrum intake on health and production parameters of fattening pigs. IPVS Belgian branch studiedag, Merelbeke, Belgium.

Declerck I., J. Dewulf, S. Piepers, and D. Maes. Factors at farm and sow level affecting colostrum quantity. Sow and litter factors affecting colostrum production. 2013. 5th ESPHM, Edinburgh, United Kingdom.

Declerck, I., C. Vanderhaeghe, and D. Maes. Incidence and prevention of early parturition and risk factors for stillborn piglets, ESDAR 2013, Bologna, Italy.

Declerck, I., J. Dewulf, S. Piepers, A. de Kruif, and D. Maes. Identification of factors at the farm, sow and piglet level associated with the colostrum intake per kg piglet. 2013. VEE studiedag, Drongen, Belgium.

Declerck I., J. Dewulf, S. Piepers, R. Decaluwé, and D. Maes. Sow and litter factors determining colostrum yield. 2014. VEE studiedag, Brussels, Belgiium.

Declerck, I., J. Dewulf, R. Decaluwé, and D. Maes. Effects of energy supplementation to neonatal low birth weight piglets on mortality, daily weight gain, weaning weight and colostrum intake. 2014. IPVS Belgian branch studiedag, Drongen, Belgium.

Declerck, I., J. Dewulf, R. Decaluwé, and D. Maes. Effects of energy supplementation to neonatal low birth weight piglets on mortality, daily weight gain, weaning weight and colostrum intake. 2016. 24th IPVS - 8th ESPHM, Edinburgh, United Kingdom.

Declerck, I., J. Dewulf, S. Sarrazin, and D. Maes. 2016. Long-term effects of colostrum intake in piglet mortality and performance. 24th IPVS - 8th ESPHM, Edinburgh, United Kingdom.

Dankwoord

DANKWOORD

Vooreerst wil ik mijn promotoren, professor Dominiek Maes en professor Jeroen Dewulf, bedanken voor de begeleiding bij dit proefschrift. Beste Dominiek, als optievakker herkauwer ben ik bij de varkens terecht gekomen, dankjewel voor deze kans en het vertrouwen. Jouw brede kennis over de varkensdiergeneeskunde en jouw begripvolle aanpak maken me dankbaar dat ik bij jou mocht doctoreren. Beste Jeroen, bedankt voor de samenwerking, jouw visie en input bij dit proefschrift. Dr. Caroline Vanderhaeghe en professor Geert Janssens, hartelijk dank voor het kritisch nalezen van dit proefschrift. Prof. Dr. A. de Kruif, hartelijk bedankt voor de geänimeerde stalrondes en de leuke bedrijfsbezoeken. Hartelijk dank dat u vandaag de taak van voorzitter op zich wilde nemen! Dear members of the exam committee, professor Cathérine Delesalle, professor Geert Janssens, professor Hélène Quesnel en doctors Caroline and Ellen, thank you for your mindful suggestions and questions during the private defence. Statistiek is een belangrijk, maar allesbehalve gemakkelijk onderdeel van een doctoraat. Gelukkig kon ik rekenen op Steven en Sofie, dankjewel!

Hartelijk dank aan alle varkenshoud(st)ers die meewerkten aan de veldstudies voor dit proefschrift. Bij de meeste onder jullie heb ik enkele nachtjes doorgebracht in de kraamstal, bedankt voor jullie gastvrijheid en jullie goede zorgen. Patrick en An, dankjewel voor jullie bezorgdheid en voor de lekkere pudding. Leuk dat onze wegen elkaar nog kruisen op feestjes ☺ Chris, Maddy, Liesbet en Charlotte, hartelijk dank voor de fijne tijd, de leuke babbels en de attente suggesties en opmerkingen. Niet alleen de locatie was top, maar jullie waren ook een super team om dergelijke intensieve studies bij uit te voeren. Louis en team (inclusief Porkie), leuk om jullie te leren kennen hebben. Bedankt voor jullie bereidwilligheid om mee te werken aan deze proef en me tijdig op de hoogte te brengen van het (eerder dan geplande) vertrek naar het slachthuis. Andy en Els, chapeau voor jullie aanpak en hartelijk dank voor de (zelfs nachtelijke) hulp. Steven en Caroline, ik heb veel bewondering en respect voor jullie. Als geen ander konden jullie exact voorspellen wanneer welke zeug zou werpen ☺ Tom en Jacqueline, respect voor jullie passie, inzet en enthousiasme voor jullie bedrijf en de ganse varkenshouderij. Bedankt voor de ontbijtjes, maaltijden en douches! Els en John, hartelijk dank voor jullie hulp en nauwgezette opvolging. Oprechte dank dat we de proef opnieuw mochten uitvoeren na de brand waarbij de vleesvarkens uit de proef omkwamen. Frank en team, bedankt voor jullie gastvrijheid en hulp. Krista, wat was het een gepuzzel om alle vleesvarkens in de juiste vrachtwagen naar het juiste slachthuis te krijgen, maar alles is uiteindelijk goed gekomen, mede dankzij Pieter en Paul, dankjewel allemaal! Kris en

Marleen, nergens verliep de proef zo vlot als bij jullie, bedankt! Ann, dankjewel voor de leuke anekdotes en jullie gastvrijheid. Filip en Veerle, jullie bevestigden dat topresultaten niet enkel in moderne kraamstallen gehaald worden. Dankjewel voor jullie gastvrijheid en leuke babbels. Davy, hartelijk dank voor jullie deelname aan deze proef en nogmaals bedankt om de varkens op Vlaams grondgebied te laten slachten. Ook al kwamen de slachthuisresultaten vandaag niet aan bod, toch wil ik hierbij de slachthuizen bedanken om mij alle varkens ook in het slachthuis te laten opvolgen: bedankt aan de mensen van Comeco, Covameat, Debra-meat, Decoster, Porc Meat, Van Landschoot, Van Gool en WestVlees. Dankjewel aan alle optie- en keuzevakkers die meehielpen bij deze veldstudies. In het bijzonder een dankjewel aan Agi, Caroline en Tommy! Jullie waren slechts met 3 studenten, maar steeds kon ik op jullie enthousiasme rekenen. Bedankt aan alle studenten voor de fijne tijd op verloskunde, buitenpraktijk of bedrijfsbegeleiding. Dankjewel aan alle collega's voor de hulp bij dit doctoraat, in welke vorm dan ook. Ruben, hartelijk dank voor de veeeeele hulp bij het waken van de zeugen, het wegen van de varkens, de bloednames, het afnemen van de longspoelsels en de hulp tijdens de slachthuisbezoeken. Bedankt voor al het gebrainstorm rond biest, de aangename bureautijd en om mij af en toe te laten ventileren (uitrazen ☺). Hopelijk kruisen onze wegen elkaar nog veel. Ik kijk er naar uit om jullie schatjes te komen bewonderen. Nog veel succes in alles wat jullie doen! Ellen en Emily, julie waren de anciens die me wegwijs maakten op de vakgroep en het varkensteam. Ik zal nooit die ene namiddag van "de" aankondigingen vergeten ☺ Ellen, als student was jij altijd 'die lieve van de varkens' en ook als collega kon ik altijd bij jou terecht. Ik moet nog steeds lachen om de aprilvisgrap, hopelijk kan jij er intussen ook al mee lachen. De collegatijd was van korte duur, maar gelukkig hadden we tweewekelijks een bij-praat-momentje tijdens vakdierenarts en hadden we nog veel contact via veepeiler varken. Bedankt voor alles, maar wellicht komen we elkaar nog veel tegen hé. An, bedankt voor de hulp bij voederanalyses, de steun en de interessante en fijne babbels. Alfonso, it was a great time with you as a student and as a colleague! I will never forget 'if the cow is dead, it is your fault' ☺ thanks! Rubén, thanks for all crazy and funny pig adventures. Josine, bedankt voor de fijne en gezellige babbels op onze bureau. Annelies S., jouw verblijf was kort, maar memorabel. Bedankt voor de vele leuke babbels en jouw ongezouten mening, je was een superfijne collega! Annelies M., jij kwam van de kleine huisdieren, maar het was snel duidelijk dat je jouw mannetje wel ging staan tussen de varkens, petje af! Bedankt om vanalles samen te regelen, te organiseren en in te springen waar nodig. Veel succes met jouw doctoraat en met jullie gezinnetje! Ik kom snel langs om Jules te komen bewonderen! Janne, bedankt voor de fijne tijd als collega's. Super dat we elk onze weg

gevonden hebben en dat onze wegen elkaar veel kruisen ☺ Bedankt voor jouw steun tot bij de laatste sprint! Tommy, bedankt voor alle hulp als student en de fijne tijd als collega's. John, thanks for the collaboration and the mindful remarks! Marlijn, Linda en Anneleen, bedankt dat ik bij jullie steeds terecht kon voor de nieuwste roddels ☺ Veel succes nog met jullie doctoraat. Klaas, bedankt om af en toe in te springen voor mij en het overnemen van mijn bedrijven. Dankjewel aan het epi-team voor de fijne babbels of beter gezegd "gestoei" Merel ☺ Bedankt Béné, Bert, Davy, Elias, Iris, Kornell, Loes, Lotte, Marilena, Marjolein, Merel en Steven. Lotte, uit het oog is niet uit het hart. Ik wou dat ik de tijd terug kon draaien naar onze tijd als collega's... weet dat ik nog heel veel aan jou denk! Steven, bedankt om de epi practica en zomercursus op jou te nemen toen ik op bevallen stond van Leonietje. Nogmaals hartelijk dank voor de vele hulp bij de statistische verwerking van de resultaten! Dankjewel aan de collega's verloskunde voor de fijne tijd op verloskunde, voor de babbels en het gezelschap tijdens de weekenddienst van buitenpraktijk. Bedankt Anita, Catharina, Davy, Emilie, Hilde, Jan Kim, Maarten, Mieke, Sarah, Sofie en Vanessa. Dankjewel Dirk, Marnik, Veronique en Willy voor jullie hulp en sympathie. Dankjewel aan de collega's van de buitenpraktijk. Bedankt Jef en Marcel om mij jullie weetjes en kneepjes aan te leren. Bedankt Anita, Bart, Cyriel, Dimitri, Ellen, Emily, Iris, Johan, Judith, Kim, Mieke, Miel en Sofie. Mieke, bedankt voor onze leuke avontuurtjes op de buitenpraktijk en jouw hulp. Ria, dankjewel voor jouw bezorgdheid, de goede zorgen, het klaarzetten van de grote (vaccin)bestellingen, de leuke babbels, de fantastische anekdotes en updates ☺ Els en Steven, bedankt voor jullie empathie en hulp bij bestellingen en pc problemen en zoveel meer. Leila en Sandra, dikke merci om keer op keer te helpen bij administratieve beslommeringen. Als erelid van het M-team voelde ik me ook thuis in het M-team. Lieve M-teamers, Ameline, Bert, Dimitri, Joren, Justine, Kristien, Marina, Wannes en Zyncke bedankt voor de superfijne tijd, de leuke babbels en mijn excuses voor de koude koffie's ☺ Joren en Kristien, oprechte dank om bij te springen op kritieke momenten zoals slachthuisbezoeken. Professor Sarne, nog steeds bloos ik bij de gedachte hoe lang ik soms stond te babbelen met een bepaald iemand van het M-team ☺ Sofie, dankjewel dat ik op je kon rekenen als tweede wacht of om in te springen op de buitenpraktijk wanneer de zeugen niet wierpen zoals gepland of er opeens varkens geladen moesten worden. Bedankt voor de zotte belevenissen zoals de zoektocht naaar de twaalf frituren in een straal van tien km rond de faculteit ☺ Veel succes met Mex, go for it!

Dankjewel aan mijn 'nieuwe' collega's van Boehringer-Ingelheim of liever mijn BI-family ☺ Bedankt voor jullie hartelijke welkom. Damienne, Guy, Niko en Monique, bedankt voor jullie begrip en steun de afgelopen weken en vandaag. Stephane, dankjewel om vandaag de tijd te vinden om er bij zijn. Bedankt aan alle vrienden en kennissen voor de interesse in mijn doctoraat, de steun en hulp. Anneleen, maatje... Ik vergeet nooit ons Duits avontuur of onze trip naar Ierland, met de vlieger ☺ We konden meerdere weken 7-7, 24-24 onder ons tweetjes stages lopen zonder één akkefietje... Je deelde steeds mee in mijn geluk en verdriet, dankjewel om zo'n fantastische vriendin te zijn! Dankjewel voor alle hulp bij de proeven, zeker die ene proef dat de zeugen wachtten op volle maan om het werpen aan te vangen ☺ Bedankt voor de gastvrijheid in Gent als ik van dienst was op de buitenpraktijk. Bedankt om zo goed te luisteren, te relativeren en mijn terug crage te geven als het wat minder ging.... Dankjewel!!! Evelyn, dankjewel voor de fijne babbels en leuke anekdotes en sorry voor het uurtje verschil... Dankjewel om mijn hulplijn bij paardenkwesties te zijn ☺ Eva, meer dan tevoren bewandelden we dezelfde weg, bedankt voor de fijne babbels en de steun. Dankjewel Lode, Wouter, Emilie en Marleen voor jullie interesse in wat ik doe en van plan was te doen ☺ Emilie, dankjewel om er vandaag bij te zijn, voor de hulp bij enkele slachthuisbezoeken en voor jouw steun. Frederik en Ellen, bedankt voor de leuke familiemomenten. Binnenkort zal er meer tijd zijn om jullie te komen bezoeken in de Ardennen. Bedankt Koen en Eveline & Koen en Caroline voor jullie interesse en de fijne babbels. Agnes, bedankt om zo'n goede oma voor onze meisjes te zijn. Bedankt dat we op jou kunnen rekenen bij onvoorziene omstandigheden. Het is zo jammer dat John er niet meer bij kan zijn, maar in ons gedachten is hij er vandaag wel bij. Pepe, bedankt voor jouw interesse en medeleven in alles wat we doen. Christiaan en mama, bedankt voor jullie hulp en steun. Ik kom zeker helpen bij de verhuis en ben alvast present op de instuif ☺ Mama, waar begin ik??? Een heel bijzondere dankjewel voor alle goede zorgen. Ondanks jouw drukke job ben je steeds paraat als oma voor onze meisjes, dankjewel!

Lorenz, bedankt om altijd in mij te geloven en voor jouw onvoorwaardelijke steun tijdens mijn studies en doctoraat. Ik kijk er heel hard naar uit om terug meer op en met de boerderij bezig te zijn. Dankjewel om zo'n fantastische papa voor onze meisjes te zijn. Marie en Leonie, jullie zijn onze trots, onze allergrootste schatten. Binnenkort ga ik heel wat verloren tijd met jullie inhalen, beloofd! Bollie, Marie en Leonie, lieve keppekes, jullie zijn het allerbeste wat mij overkomen is, weet dat ik jullie oneindig graag zie!!

Dankjewel!